AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

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300.

(Vol. XIV.—April, 1885.)

RECORD OF TESTS OF CEMENT MADE FOR BOSTON MAIN DRAINAGE WORKS, 1878-1884.

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PRESENTED APRIL 15TH, 1885.

The construction of a system of intercepting and outfall sewers for the city of Boston, Mass., was begun in the fall of 1877. The works required to complete the system included about 17 miles of large sewers, a pumping station and a reservoir. The principal materials entering into these structures were brick, stone and concrete masonry. About 180 000 barrels of cement were required to build this masonry, and to insure its stability and durability it was necessary that the cement should be of good quality. From the start, therefore, means for determining the qualities of all cements used or offered for use were provided. A room was set apart for these operations and an inspector appointed to conduct them.

The tests were devised, principally, in order to determine three points, namely :

1. The relative strength and value of any cement as compared with the average strength and value of the best quality of similar kinds of cements.

2. The absolute and comparative strength and value of mortars of different kinds made from the same cement.

3. The effect produced upon the strength of any cement mortar by different conditions and methods of treatment.

This knowledge was chiefly sought by observations of the tensile strength of the cements and mortars tested. Reasons for adopting the tensile test were that it required comparatively light strains to produce rupture; that, as it was universally used, it afforded results which could be compared with those of other observers, and, finally, because the tensile stress is precisely that by which the mortar of masonry, in most cases of failure, actually is broken.

All the particles of any cement are of appreciable size, and its strength as a mortar depends on the extent to which the particles adhere, at their points of contact, to each other or to some inert substance. This adherence may be overcome and the mortar broken, either by pulling the particles apart by tension or by pushing them past each other by compression. The effect upon the adhering quality of the particles is not very different in the two operations, but in the latter the friction of the particles against each other must also be overcome, which requires the application of very much more force. Transverse tests are only tensile tests differently applied, and shearing produces a stress intermediate to tension and compression. When masonry is strained, one part of it is in tension another in compression, and, as mortar yields more readily to tensile stress, failure generally occurs by rupture of the joints in tension.

Briquettes for testing, with a breaking section of one square inch, were first used, but it was thought that these, from their small size, were liable to be strained and injured by handling in taking them from the moulds and transferring them to the water. A larger pattern with a breaking section one and one-half inches square or two and one-quarter square inches was finally adopted. Comparative tests with briquettes of one inch and two and one-quarter inches section respectively indicated that there was little, if any, difference in their strength per square inch.

The shape of the briquette adopted is shown by Fig. 2, Plate II.

Fig. 1 of the same plate shows the brass moulds in which the mortar was packed to form the briquettes. These moulds proved very satisfactory. They were strong, and easily clamped and opened. The clamp consisted of a piece of brass wire riveted loose in the projecting lug of one branch of the mould, and binding by friction when turned against the wedge-shaped lug on the other branch. If a fastening worked loose, a single tap of the hammer would tighten it. All breaking loads were reduced to pounds per square inch of breaking section by multiplying by four and dividing by nine.

Before testing a cement its color was first observed. The absolute color of a natural cement indicates little, since it varies so much in this particular. But for any given kind, variations in shade may indicate differences in the character of the rock or in the degree of burning. With Rosendale cements a light color generally indicated an inferior or under-burned rock. An undue proportion of under-burned material was indicated in the case of Portland cement by a yellowish shade, and a marked difference between the color of the hard-burned, unground particles retained by a fine sieve and the finer cement which passed through the sieve.

The weight per cubic foot was also sometimes ascertained. As this would vary with the density of packing, a standard for comparison was adopted, which was the density with which the cement would pack itself by an average free fall of three feet. The apparatus used is shown by Fig. 3, Plate II. The cement was placed in a coarse sieve on the top of a galvanized iron tube, and, the sieve being shaken, the cement sifted through the tube into the box below. This box held exactly one-tenth of a cubic foot when struck level with its top.

The weights per cubic foot as determined by this method varied considerably with different kinds and brands of cement, and somewhat with different samples of the same brand. The averages were as follows:

TABLE No. 1.

Rosendale	49 to 56	pounds.
Lime of Teil	50	"
Roman	54	"
A fine-ground French Portland	69	"
English and German Portlands	77.5 to 87	"
An American Portland	95	"

The following table shows the effect of fine grinding upon the weight of cement. It gives the weight per cubic foot of the same German Portland cement containing different percentages of coarse particles as determined by sifting through the No. 120 sieve :

TABLE No. 2.

0	per cent.	retained by	No. 120 sieve—W't	per cubic	foot...	75 pounds.
10	"	"	"	"	"	79 "
20	"	"	"	"	"	82 "
30	"	"	"	"	"	86 "
40	"	"	"	"	"	90 "

It was soon discovered that there was no direct ratio between weight and strength. As a general rule, subject to exceptions, heavy cement, if thoroughly burned and fine-ground, was preferred to light cement. Fine-ground cements were lighter than coarse-ground, and under-burned rock lighter than well burned. While color and weight by themselves indicated little, yet considered together and also in connection with fineness, they enabled the inspector to guess at the character of a cement and suggested reasons for high or low breaking. A cement which was light in color and weight, and also coarse-ground, would be viewed with suspicion.

The test of fineness, which followed, was considered of great importance, as showing the quantity of actual cement contained in a barrel, and its consequent value. Small scales were used, made for this purpose by Fairbanks & Co. One-quarter of a pound of the sample was weighed out and passed through the sieve. The coarse particles retained by the sieve were returned to the scales, whose balance beam carried a movable weight and was graduated in percentages of one-quarter pound. The percentage of coarse particles retained by the sieve could thus be read directly from the beam.

Standard sieves, varying from No. 50 to No. 120, were used. The number of meshes to the lineal inch in any sieve is commonly supposed to correspond with its trade number. As sold, however, they vary somewhat, and the number of wires is generally less, by about ten per cent., than the number of the sieve. A No. 50 sieve commonly has about 45 meshes to the inch and a No. 120 about 100, or a few more. In important contracts, where a certain degree of fineness was called for, it was

customary carefully to compare two sieves and retain one, which was specified as the standard, while the other was delivered to the manufacturer for his guidance.

In accordance with common practice, the No. 50 sieve was first used. It was soon discovered, however, that so coarse a sieve did not always give a correct indication of the fineness of the cement. This was especially true of Portland cements. Some brands, chiefly German, were evidently bolted by the manufacturers with special reference to tests by this sieve, in which they would leave no residuum. Yet the bulk of such cements, while containing no very coarse particles, might prove quite coarse when tested by the No. 120 sieve.

It is obvious that pieces of burned cement slag $\frac{1}{4}$ of an inch in diameter would have no cementing quality, and the same is true of particles $\frac{1}{100}$ of an inch in diameter. At precisely what smaller size the particles begin to act as cement it was impossible to determine. Those retained by a No. 120 sieve, in which the open meshes are approximately $\frac{1}{200}$ of an inch square, were found to have some slight coherence, even after washing to remove the finer floury cement which was sticking to them. It was also found that the No. 120 sieve was about as fine a one as it was practicable to use, on account of the time required to sift the cement through it. It was, therefore, adopted as a standard.

Assuming (what was only approximately verified by experiments on tensile strength) that only what passed through this sieve had real value as cement, and that the rest was not very different from good sharp sand, the difference in the quantity of actual cement obtained in purchasing barrels 60 and 90 per cent. fine, respectively, is shown by Figs. 9 and 10, Plate II. This has an important bearing on the proportion of sand to be added in practical use; for when mortar is mixed for use in the proportion of one barrel of cement to two of sand, if there be nine parts of cement and one of sand in the barrel of cement itself, the actual proportion in the mortar will be .9 to 2.1 or 1 to 2.33. If there be only six parts of cement and four of sand in the barrel of cement, the resulting proportion in the mixture will be .6 to 2.4 or 1 to 4.

Fine cement can be produced by the manufacturers in three ways: by supplying the mill-stones with comparatively soft, under-burnt rock, which is easily reduced to powder; by running the stones more slowly, so that the rock remains longer between them; or by bolting through a sieve and returning the unground particles to the stones. The first

process produces an inferior quality of cement, while the second and third add to the cost of manufacturing.

The extra cost, as estimated by a firm of English manufacturers, of reducing a Portland cement from an average of 70 per cent. fine, tested by No. 120 sieve, to 90 per cent. fine, was 18 cents per barrel. The price at which 5 000 barrels of their ordinary make, 70 per cent. fine, were offered, delivered on our work, was $2.82 per barrel. The same cement, ground 88 per cent. fine, was delivered for $3 a barrel. On the foregoing assumption of the value of fine and coarse particles, the city, by accepting the first offer, would have obtained in bulk 3 500 barrels of actual cement and 1 500 barrels of sand for $14 100. By accepting the second offer, it obtained in bulk 4 400 barrels of cement and 600 of sand for $15 000. That is, the 900 additional barrels of cement cost one dollar a barrel. Experiments illustrating the value of fine grinding and further comments will be given later.

Tests were made both of neat cement and of cement mixed with sand in different proportions. The latter were preferred because they showed the strength and value of the mortars used in actual work. It was found also that the strength of briquettes made of neat cements did not always indicate the capacity of these cements to bind sand, or the strength of the mortars made with them. This is illustrated by experiment No. 10, on page 157.

The greater the proportion of sand, in the mortar tested, the more accurately was the actual cementing quality of the cement indicated. As, however, very weak mixtures took a long time to harden, and were liable to injury from handling, one part cement to three parts sand was adopted as the usual mixture for testing Portland cements, and one to one and one-half or two for American cements. Occasionally, when testing large quantities of some well-known brand, the object being to see that a uniform strength was maintained, it was found sufficient, and simpler, to omit the sand and make the briquettes of cement only.

In making mortars for testing, rather coarse, clean, sea-beach sand was used.

The subsequent strength of the briquettes depended largely upon the amount of water with which they were gauged. The highest results were obtained by using just enough water thoroughly to dampen the cement, giving the mass the consistency of fresh loam, which became pasty by working with a trowel. For ordinary testing, sufficient water

was added to make a plastic mortar somewhat stiffer than is commonly used by masons. Different cements varied in the amounts of water needed to produce this result. As a rule, American cements needed more water than Portland, fine-ground more than coarse, and quick-setting more than slow-setting cements. Experiment No. 9, page 156, shows the comparative strength of mortars gauged with different percentages, (in weight of the cement), of water. The standard adopted was 25 per cent. for Portland cement and 33 per cent. for Rosendale, but these amounts were increased or diminished by the operator to suit the circumstances, his aim being to obtain mortars of unvarying consistency.

The way in which the test briquettes were made was as follows: The moulds, having been slightly greased inside to prevent the mortar sticking to them, were placed on a polished marble slab. This support for them was used because it was easily cleaned and the mortar did not stick to it. Experiment No. 6, page 153, shows that the use of porous or of non-porous beds to support the moulds does not materially affect the strength of the mortars. The requisite amounts of cement and sand for one briquette were weighed out and incorporated dry in a mixing-pan. The proper amount of water was also weighed out and added, and the mass worked briskly with a small trowel until of uniform consistency. A brass mould was half filled with the mortar, which was rammed into place by the operator with a small wooden rammer, in order to displace any bubbles of air which might be confined in it. The mould was then filled to its top with the remaining mortar, which was in turn rammed down. Finally the mortar was struck even with the top of the mould and given a smooth surface by the trowel.

The amount of mortar packed in the mould and the consequent density of the briquette would vary with any variation in the degree of force exerted by the operator in ramming. This variation was reduced to a minimum by always mixing a fixed amount of mortar, which was barely more than sufficient to fill one mould. Irregularities in ramming would thus be detected by variations in the amount of surplus mortar, and could be checked. An attempt was made to do away wholly with this element of uncertainty by pressing the mortar into the moulds with certain fixed pressures. Apparatus was devised and used for this purpose, but was finally abandoned on account of the length of time required for its use.

The initial energy of the cement—that is, the length of time after mixing before it "set"—was determined by noting the length of time before it would bear "the light wire" of $\frac{1}{12}$-inch in diameter loaded with $\frac{1}{4}$-pound weight, and also "the heavy wire" $\frac{1}{24}$-inch in diameter loaded with 1-pound weight. At the former time, the cement was said to have begun to set; and at the latter, it was entirely set. Different kinds and brands of cement varied greatly in the time after mixing when they would bear the wires. Some brands of English Roman cement would set in two minutes; and some of Portland required over 12 hours. Cold retarded the setting; and fresh-ground cements set quicker than older ones. No direct relation was established between initial energy and subsequent strength. By judicious mixing of quick and slow setting cements, a mixture could be obtained which would set within any desired period.

As soon as the briquettes were hard enough to handle without injury, which with different cements and mixtures varied from 5 minutes to 12 or more hours, they were removed from the moulds and placed in numbered pans filled with water. Before removal each briquette had marked upon it, with steel stamps, the name of the cement, date of mixing, and a number by which it could be further identified. The inscription might read thus:

"Alsen 1–3. May 17, 1880. 47."

Records were also kept in books and on blanks provided for the purpose. The briquettes were kept in the pans, covered with water, until they were broken. Their age when broken varied from 24 hours to 5 years.

In testing a well-known American cement, of generally uniform quality, if it were an object to save time, the comparative excellence of the samples could be sufficiently determined by a 24-hours test of briquettes made of neat cement. Under similar conditions neat Portland cement could be tested in 7 days. To test mortar of either kind of cement took a week—or, better, a month—especially if there was a liberal proportion of sand.

The probable value of an untried brand of cement could hardly be ascertained with certainty in less than a month, and not always then. To illustrate the occasional need of long-time tests, a case may be cited.

A new brand of cement, made by some patent process, was offered for use on the work. When tested it set up well, and at the end

of a week the neat cement had a tensile strength of 184 pounds per square inch. In a month this had increased to 267 pounds, indicating a strength equal to that of a low-grade Portland cement. At this time there was nothing in the appearance of the briquettes to indicate any weakness. Yet after about 6 months they fell to pieces, and had entirely lost their cohesive quality.

The briquettes were broken by a machine made for the Department by Fairbanks & Co. It worked with levers, acting on a spring balance, which was tested from time to time, and found to maintain its accuracy.

During the progress of the work the following brands of cement were submitted for approval, and were tested with more or less thoroughness:

Old Newark, Newark and Rosendale, Norton, Heffman, Old Rosendale, New York and Rosendale, Lawrenceville, Rosendale, Arrow, Keator, Howe's Cave, Rock Lock, Buffalo, Cumberland, Round Top, Selenitic, Vorwholer, Star, Dyckerhoff, Alsen, Hemmor, Bonnar, Onward, Burham, J. B. White, Knight, Bevan & Sturge, Brooks, Shoobridge & Co., Leavitt, Grand Float, Diamond, Spanish, Red Cross, La Farge, Lime of Teil, Saylor, Coolidge, Walkill, Cobb, Abbott.

The following is a record of the more instructive tests made for experimental purposes. Nearly all of them were made with special reference to the work then in hand, to elucidate some practical questions affecting the purchase, testing or use of the cements needed for building purposes. The names of the brands of cement tested in the several experiments are generally omitted. This is in order to avoid any unwarranted use of the results as recorded.

The figures given in the tables always represent average breaking loads in pounds per square inch of breaking section.

Experiment No. 1.

Of natural American cements, the Rosendale brands (so-called) are the only ones which find a sale in the Boston market, and they were chiefly used on the work. Imported Portland cements were also largely used. It was important, therefore, to ascertain the actual and comparative strengths of these cements. The following table gives results compiled from about 25,000 breakings of twenty different brands, and fairly represents the average strength of ordinary good cements of the two kinds. Some caution, however, is necessary in using the table as a

standard with which to compare other cements. Quick-setting cements might be stronger in a day or week, and show less increase in strength with time. Fine-ground cements would probably give lower results tested neat, and higher ones with liberal proportions of sand.

TABLE No. 3.

Neat Cement.					Cement, 1; Sand, 1.				Cement, 1; Sand, 1.5.				Cement, 1; Sand, 2.				Cement, 1; Sand, 3.				Cement, 1; Sand, 5.			
1 Day.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.
ROSENDALE CEMENT.																								
71	92	145	282	290	56	116	190	256	41	95	155	230	24	60	125	180	14	35	80	121	5	16	46	80
PORTLAND CEMENT.																								
102	303	412	468	494	160	225	347	387	..	..	...	...	126	163	279	323	95	140	198	257	55	88	136	155

The table is instructive in several ways. It shows that Portland cement acquires its strength more quickly than Rosendale; that both cements (but especially Rosendale) harden more and more slowly as the proportion of sand mixed with them is increased; that whereas neat cements and rich mortars attain nearly their ultimate strength in six months or less, weak mortars continue to harden for a year or more. The table shows the advantage of waiting as long as possible before loading masonry structures, and the possibility of saving cost by using less cement when it can have ample time to harden. It also shows that Portland cement is especially useful when heavy strains must be withstood within a week.

Experiment No. 2.

These series of tests are like the preceding ones, except that a single brand of cement was used in making each. The average breaking loads per square inch were obtained from a less number of briquettes (about 500 in all), mortars with larger proportions of sand were included in the series, and the tests were extended for two years.

TABLE No. 4.

Age when Broken.	Neat Cement.	Cement 1, Sand 2.	Cement 1, Sand 4.	Cement 1, Sand 6.	Cement 1, Sand 8.	Cement 1, Sand 10.	Cement 1, Sand 12.
PORTLAND CEMENT MORTAR.							
One week ...	295	166	89	50	33	23	17
One month...	341	243	132	88	67	50	41
Six months...	374	343	213	149	98	76	51
Two years....	472	389	226	159	98	49	31
ROSENDALE CEMENT MORTAR.							
One week....	....	24	7	5	....	....	....
One month...	....	83	32	17	8	5	....
Six months...	....	172	93	62	50	33	21
Two years....	....	211	90	56	33	22	20

The tables show that considerable strength is acquired in time, even when a very large proportion of sand is used; also, that most mortars increase very little, if any, in tensile strength after six months or a year. They become harder with time, but also become more brittle and probably less tough. Specimens of mortar two years old or more break very irregularly.

Experiment No. 3.

The rate at which Rosendale and Portland cements, respectively, increase in strength during the first two months after mixing is very different, and has some bearing on their use, and more on the interpretation of tests of them made within that period. The curves, Fig. 1, Plate III, which indicate this rate of increase, were compiled from tests with neat cement. It is probable that tests with mortar would give somewhat similar results. By comparing the two curves, it appears that

after 24 hours Rosendale cement has about ¾ of the strength of Portland. While the latter increases greatly in hardness during the next few days, the energy of the former becomes dormant, so that at the end of a week the Portland cement is more than three times as strong as the Rosendale. During the second week the Portland cement increases more slowly, and the Rosendale continues nearly quiescent. At about this period, and for the next six weeks, the Rosendale cement gains strength, not only relatively, but actually faster than the Portland, so that when 2 months old the former has ½ the strength of the latter. After 2 months the relative rate of increase and the comparative strength of the two cements remain nearly unchanged. A series of tests with a Buffalo cement, and one with a Cumberland cement, gave results similar to those with Rosendale cement.

Experiment No. 4.

For making tests it is not always convenient to obtain sand of uniform size, and still less so to obtain such sand in sufficient quantities for use in work. The curves, Fig. 2, Plate III, record some tests made to determine the effect of fineness and of uniformity of size in sand upon the strength of mortars made with it.

The curves show that for comparative tests it is advisable to have sifted sand of nearly uniform size; that mortars made with coarse sand are the strongest, and that the finer the sand the less the strength. It also appears that mixed sand, *i. e.*, unsifted sand containing a mixture of particles, from coarse to fine, makes nearly as strong a mortar as coarse or medium coarse sand. For use in work, therefore, it is well to avoid fine sands, but it is not necessary to have sand of uniform size, or to sift out a moderate proportion of fine particles.

Experiment No. 5.

As some experimenters on cement use a test briquette with a breaking section of 1 square inch, and others one with a section of 2¼ square inches, the following experiment was made to determine the difference, if any, in the strength acquired by the same mortars moulded into briquettes of these different sizes. Two series of tests were made, in the same way, with the same mortars. In one series the briquettes had a breaking section of 1 square inch, and in the other the section was 2¼ square inches. The results are given in the following table, in which

the figures represent breaking loads in pounds per square inch, and are averages from 5 breakings.

TABLE No. 5.

	Rosendale Cement.							Portland Cement.					
	Neat Cement.				Cement 1, Sand 1.5.			Neat Cement.			Cement 1, Sand 1.5.		
	1 Day.	1 Week.	1 Month.	6 Months.	1 Week.	1 Month.	6 Months.	1 Week.	1 Month.	6 Months.	1 Week.	1 Month.	6 Months.
1-inch Section	49	73	156	286	27	53	236	309	460	657	60	96	175
2¼-inch Section	49	78	173	258	27	62	311	347	391	578	67	108	230

As is usual, the breaking loads are somewhat irregular, the inch section excelling at some points, and the larger section at others. The experiment, however, seems to indicate that neither size will, as a rule, give higher results than the other.

Experiment No. 6.

Some experimenters have thought it important to place the moulds in which mortar is packed for testing upon a porous bed, such as blotting paper or plaster. Others use a non-porous bed of glass, slate or marble. The following series of tests were made to discover the effect of these different modes of treatment. The figures in the tables represent breaking loads, in pounds per square inch, and are averages of about ten breakings.

TABLE No. 6.

ROSENDALE CEMENT.

Mixture.	Kind of Bed.	One Week.	One Month.	Six Months.	One Year.
Neat,	Marble.....	95	151	288	325
	Plaster.....	106	178	303	316
Cement, 1,	Marble.....	44	107	210	251
Sand, 1.5,	Plaster.....	62	120	219	265

A CUMBERLAND CEMENT.

Mixture.	Kind of Bed.	One Day.	One Week.	One Month.	Six Months.	One Year.
Neat,	Marble.......	128	133	142	231	241
	Plaster.......	147	165	176	244	257
Cement, 1,	Marble........	....	107	161	275	339
Sand, 1.5,	Plaster.......	....	128	166	299	345
Cement, 1,	Marble.......	....	85	134	201	292
Sand, 2,	Plaster.......	....	111	148	241	294
Cement, 1,	Marble.......	....	40	94	162	163
Sand, 4,	Plaster.......	....	46	91	164	170

GERMAN PORTLAND CEMENT.

Mixture.	Kind of Bed.	One Week.	One Month.	Six Months.	One Year.
Cement, 1,	Marble......	259	367	390	....
Sand, 1,	Plaster......	213	376	411	....
Cement, 1,	Marble......	176	256	346	345
Sand, 2,	Plaster......	196	258	326	357
Cement, 1,	Marble......	141	225	250	313
Sand, 3,	Plaster......	147	220	258	312
Cement, 1,	Marble......	103	157	240	274
Sand, 4,	Plaster......	120	150	233	264
Cement, 1,	Marble......	82	108	182	213
Sand, 5,	Plaster.....	103	140	193	197

Making allowance for a few irregularities, it appears from the foregoing tables that the use of a porous bed gives slightly higher results for the first one or two months, but that the difference disappears or becomes insignificant with age.

Experiment No. 7.

It is a well-recognized fact that in experimenting with cements, even when great care is exercised, individual specimens break very irregularly, and that results even approximately conforming to theory can only be obtained from averages from a large number of breakings. The personal equation of the operator and the degree of force with which he presses the mortar into the moulds is one factor in producing irregular results. To do away with this, a machine for packing the moulds was devised and used for a time. By this the mortar was pressed into the moulds by a metallic plunger, acting with definite pressures varying from 50 to 400 pounds.

The machine-made briquettes broke with somewhat greater uniformity than hand-made ones. So much more time was required to make briquettes with this machine that it was found to be impracticable to employ it for general use.

Experiment No. 8.

By the sea it is frequently convenient to mix mortar with salt water. Brine is also used in winter as a precaution against frost. This experiment was made to obtain the comparative effect of mixing with and immersing in fresh and sea water respectively. The tests were made upon a Rosendale mortar, mixed one part cement to one part sand, and an English Portland mortar, one part cement to two parts sand. The figures are averages of about ten breakings, and give the tensile strength in pounds per square inch with different methods of treatment and at different ages.

Except for some irregularity in the breakings for one year (which may have been due to the manipulation), the table indicates that salt, either in the water used for mixing or that of immersion, has no important effect upon the strength of cement. Salt water retards the first set of cement somewhat.

TABLE No. 7.

Rosendale Cement Mortar, 1 to 1.					Portland Cement Mortar, 1 to 2.			
Fresh Water.	Fresh.	Salt.	Salt.	Mixed with	Fresh.	Fresh.	Salt.	Salt.
Fresh Water.	Salt.	Fresh.	Salt.	Immersed in	Fresh.	Salt.	Fresh.	Salt.
40	48	50	61	One week.	151	122	152	149
126	135	114	126	One month.	213	191	203	200
247	250	243	224	Six months.	314	245	277	264
310	263	224	217	One year.	342	231	346	295

Experiment No. 9.

This was an experiment to determine the relation existing between the stiffness of cement mortar when first mixed and its subsequent strength. The stiffness depends on the proportion of water used in mixing, and varies somewhat with different cements. Natural American cements take up more water than Portland cements, and fine-ground more than coarse cements. Many series of tests bearing on this point were made. The results obtained from two of the more complete series are shown by the curves on Plate IV. The cements used in these tests were a rather coarse English Portland and a fair Rosendale. Each of the points in the curves represents an average from about ten briquettes. The cements were tested neat, and the amounts of water used were different percentages, by weight, of the amounts of cement. The resulting stiffness of mortar is indicated on the curves. This varied from the consistency of fresh loam to a fluid grout. The time of setting is greatly retarded by the addition of water.

The curves show that from 20 to 25 per cent. of water gives the best results with Portland cement, and from 30 to 35 per cent. with Rosendale; that the differences in strength due to the amount of water are considerable at first, but diminish greatly with age; that the soft mortars, even when semi-fluid like grout, attain considerable strength in time.

Experiment No. 10.

From the first it was observed that fine-ground cements were less strong when tested neat, and stronger when mixed with sand, than were coarse cements. A few examples of this are given below. In the first table a coarse English Portland cement is compared with a fine-ground French Portland. The per cent. of each retained by the fine No. 120 sieve is given, and the tensile strength, in pounds per square inch at the end of 7 days.

TABLE No. 8.

Kind of Cement.	Per cent. retained by No. 120 Sieve.	Parts of Sand to 1 part of Cement.				
		0	2	3	4	5
English Portland.............	37	319	125	89	59	43
French Portland.............	13	318	205	130	114	86

Such examples could be multiplied. German Portland cements were commonly finer ground than English and, as a rule, were no stronger, or less strong, tested neat, but were much stronger with liberal proportions of sand. In the following table two lots of the same brand of English Portland cement are compared. The coarse cement was the ordinary make of the manufacturers; the fine cement differed in no particular from the other except that it was ground more slowly and finer, to meet the requirements of a special agreement. The age of the samples when broken was 28 days.

TABLE No. 9.

Kind of Cement.	Per cent. retained by No. 120 Sieve.	Parts of Sand to 1 part of Cement.		
		0	3	5
Ordinary Cement..........	35	403	105	68
Fine-ground Cement......	12	304	180	96

Different brands of Rosendale cement varied considerably in their fineness. Those of the best reputation would leave from 4 to 10 per cent. residuum in the No. 50 sieve; other brands would leave in the same sieve from 10 to 23 per cent. In the following table is compared the average tensile strength obtained from experiments with three of the finer ground brands, and also with three other brands of good reputation, but more coarsely ground. The age of the specimens was 1 week.

TABLE No. 10.

Kind of Cement.	Per cent. retained by No. 50 Sieve.	Parts of Sand to 1 part of Cement.		
		0	1.5	2
Fine Rosendale...........	6	92	41	25
Coarse Rosendale..........	17	98	29	16

The foregoing experiments show that it is impossible, by tests on the tensile strength of neat cements alone, to judge of their value in making mortar for practical use; also that fine-ground cements make stronger mortars than do coarser ones.

A number of series of tests were made of cements which had been sifted through sieves of different degrees of fineness, and had thereby had different percentages of coarse particles removed from them. The

results from these experiments were quite uniform and showed that, in proportion as its coarse particles were removed, a cement became more efficient for making mortars with sand. The following table gives the results obtained from one such series of tests made with an English Portland cement. In the experiment comparison is made between the strength of mortars made with the ordinary cement, unsifted as it came from the barrel, and those made with the same cement after having been sifted through Nos. 50, 70, 100 and 120 sieves, which, respectively, eliminated more and more of the coarse particles. The per cent. of particles which would still be retained by the fine No. 120 sieve, after sifting through the coarser sieves, is given in the second column of the table. There is included in the table an extra coarse cement, which was made so by adding to unsifted cement a certain amount of the coarse particles taken from the sifted cements. The tensile strength is given in pounds per square inch.

TABLE No. 11.

Kind of Cement used in making Mortars.	Per cent. of particles retained by No. 120 Sieve.	One Week.				One Month.				Six Months.				One Year.			
		Parts of Sand to 1 part of Cement.															
		2	3	4	5	2	3	4	5	2	3	4	5	2	3	4	5
Cement with coarse particles added	55	72	39	32	19	117	80	67	40	210	135	122	84	200	128	112	92
Ordinary Cement, unsifted	33	129	92	58	43	197	143	109	88	311	236	183	136	288	247	168	165
Cement which passed No. 50 Sieve	28	159	97	67	47	210	158	125	102	324	246	190	146	328	249	214	178
Cement which passed No. 70 Sieve	18	163	117	82	65	239	168	151	112	338	256	225	173	342	295	230	193
Cement which passed No. 100 Sieve	8	177	123	84	73	255	185	156	122	257	288	239	182	382	307	257	215
Cement which passed No. 120 Sieve	0	198	154	95	86	271	200	161	132	379	320	238	196	386	316	262	218

In a similar series of tests with Rosendale cement mortars the increase in strength obtained by substituting fine for coarse particles in the cement was much less marked. The coarse particles were softer than those from Portland cement and had, in themselves, some power of cohe-

sion. As previous tests had shown that fine-ground Rosendale cements were stronger, with sand, than coarse-ground, it was assumed that the superiority was due, not so much to the absence of palpably coarse particles, as to the fact that the bulk of the cement was more floury and thus better adapted to coating and binding the particles of sand. Probably natural American cement is as much improved as is Portland cement by fine grinding, but in the case of the former there would not be the same relative advantage in bolting out the coarse particles after grinding.

The following series of tests may be of interest on account of the age of the specimens. The mortars were made with an English Portland cement, both unsifted as taken from the cask, and also after it had been sifted through the No. 120 sieve, by which process about 35 per cent. of coarse particles were eliminated.

TABLE No. 12.

Kind of Cement.	Neat Cement.		Cement, 1; Sand, 2.		Cement, 1; Sand, 5.	
	2 Years.	4 Years.	2 Years.	4 Years.	2 Years.	4 Years.
Ordinary Cement, unsifted..	603	387	339	493	182	202
Cement which passed No. 120 Sieve....................	374	211	478	580	250	284

This table also shows that fine cements do not give as high results tested neat as do cements containing coarse particles, even coarse particles of sand. It also shows (what is often noticed) that neat cements become brittle with age, and are apt to fly into pieces under comparatively light loads.

The series of tests which follows was made for the purpose of ascertaining what value, if any, for cementing purposes, was possessed by the hard, coarse particles of Portland cement. Mortars were made with an ordinary English Portland cement, and compared with similar mortars made with the same cement, after sifting through No. 120 sieve, which retained 33 per cent. of coarse particles.

TABLE No. 13.

Kind of Cement.	One Week.			One Month.			Six Months.			One Year.		
	Parts of Sand to one part of Cement.											
	0	2	3	0	2	3	0	2	3	0	2	3
Ordinary Cement, unsifted........	353	139	86	279	201	142	438	323	253	444	343	271
Cement which passed No. 120 Sieve..........................	311	187	132	243	275	201	268	367	310	306	434	333

As usual, the coarse cement was stronger neat, and weaker with sand. Assuming that the 33 per cent. of coarse particles retained by the sieve had *no* value as cement, acting merely as so much sand, and assuming also that all which passed through the sieve was good cement, it follows that the ordinary unsifted cement with two parts of sand made a mortar in which the proportion of real cement to sand was .67 to 2.33, or about 1 to 3.5. Hence, the mortar made with fine cement and three parts of sand should be as strong, or a little stronger, than that made with the coarse cement and two parts of sand. It will be seen that the results in the table sustain the assumption very well.

If, then, the coarse particles are assumed to act merely as so much sand, it will not lessen the efficiency of the cement to remove its coarse particles, and to substitute actual sand in their place. This was done in making the following series of tests. One set of briquettes was made with ordinary cement, and another set with the same cement from which 33 per cent. of coarse particles had been removed and replaced with fine sand.

TABLE No. 14.

Kind of Cement.	One Week.		One Month.		Six Months		One Year.	
	Parts of Sand to one part of Cement.							
	2	3	2	3	2	3	2	3
Ordinary Cement, unsifted...........	139	86	201	142	324	253	343	271
Cement with 33 per cent. coarse particles removed and fine sand substituted..........................	101	67	160	100	253	206	305	240

These briquettes refused to break in accordance with the theory, and the assumed hypothesis was not verified. It is evident that, for making mortar, the coarse particles of Portland cement are superior to ordinary sand, but much inferior to fine cement. In the mortars made with the cement in which the coarse particles had been replaced with fine sand, the real proportions of cement to sand were 1 to 3.5 and 1 to 5. It will be noticed that the tensile strength was not reduced in like proportion.

Experiment No. 11.

While building masonry laid in American cement mortar, it is sometimes desirable to increase the strength of the mortar temporarily or in places. Rich Portland cement mortars are expensive, and those with large proportions of sand are too porous for many purposes. The desired strength can be gained by using, instead of the simple American cement, the same cement mixed with a percentage of strong Portland cement.

The following series of tests was designed to ascertain the comparative strength of mortars made with a Rosendale cement, an English Portland cement, and also a mixture composed of equal parts of each.

TABLE No. 15.

Kind of Mortar.	1 Week.	1 Month.	6 Months.	1 Year.
Rosendale Cement, 1; Sand, 2.....	26	60	125	180
Rosendale Cement, 0.5. Portland Cement, 0.5. } Sand, 2.	79	138	268	273
Portland Cement, 1 ; Sand, 2.....	126	163	279	323

In the foregoing tests the mortar made with mixed cement had an unexpected strength approximating to that of mortar made with pure Portland cement. In the following series of tests of mortars made with lime of Teil, a fine-ground French Portland cement, and the lime and cement mixed, the strength of the mortar made with the mixture is almost exactly a mean between those of the other two mortars, as also the cost of the mixed cement is a mean between the costs of the other two.

TABLE No. 16.

Kind of Mortar.	1 Week.	1 Month.	6 Months.	1 Year.
Lime of Teil, 1; Sand, 2..........	40	65	150	195
Lime of Teil, 0.5. Portland Cement, 0.5. } Sand, 2...	100	135	255	290
Portland Cement, 1 ; Sand, 2.....	170	265	350	365

The best Portland cements sometimes do not set within an hour, which precludes their use for wet work. In such cases quick-setting cement should be added to them. Roman cements can be procured which will set in from one to five minutes. Mixtures of Roman and Portland cements were often used on the Main Drainage works. Such mortars would set about as quickly as if made with Roman cement alone, and would acquire great subsequent strength due to the Portland cement contained in them. This was proven by many experimental tests.

It is probable that mixtures of any good cements can be used without risk, but before adopting any novel combination it would be wise to test it experimentally.

Experiment No. 12.

Engineers are accustomed to require that only clean sand and water shall be used in making mortar. Occasionally these requirements cause delay and extra expense. This experiment was designed to ascertain how much injury would be caused by the use of sand containing moderate proportions of loam. In mixing the mortar for these briquettes, sand containing 10 per cent. of loam was used in the place of clean sand. Each figure in the table is an average (in pounds per square inch) of ten breakings.

TABLE No. 17.

Rosendale Cement, 1; Sand, 1.5; Loam, 0.15.

One Week.	One Month.	Six Months.	One Year.
21	46	200	221

The tests do not give very decisive results. For one week and one month, the breaking loads are not much more than one-half what would have been expected with clean sand. For six months and a year, they are fully equal to ordinary mortar.

Experiment No. 13.

This experiment was similar to the foregoing one except that clay instead of loam was added to the mortar. Clay when dissolved or pulverized consists of an almost impalpable powder, with particles fine enough to fill the interstitial spaces among the coarser particles of cement. By adding clay to cement mortar a much more dense, plastic and water-tight paste is produced, which was occasionally found convenient for plastering surfaces or stopping leaky joints. Each figure in the Portland cement series of tests is an average from about 15 briquettes; those in the Rosendale cement series are averages from 10 briquettes.

TABLE No. 18.

ROSENDALE CEMENT.

	Cement, 2 Clay, 1	Cement, 1 Clay, 1	Cement, 1 Sand, 1.5	Cement, 1 Sand, 1.5 Clay, 0.15	Cement, 1 Sand, 1.5 Clay, 0.3	Cement, 1 Sand, 1.5 Clay, 0.45
1 week...	32	23	50	52	34	33
1 month..	108	52	123	116	101	100
6 months.	303	206	217	248	247	236
1 year....	208	209	262	290	265	261

PORTLAND CEMENT.

	Cement, 2 Clay, 1	Cement, 1 Clay, 1	Cement, 1 Sand, 2	Cement, 1 Sand, 2 Clay, 0.2	Cement, 1 Sand, 2 Clay, 0.4	Cement, 1 Sand, 2 Clay, 0.6
1 week....	185	192	150	197	185	145
1 month..	263	271	186	253	245	203
6 months.	348	322	320	361	368	317
1 year....	303	301	340	367	401	384

The tests seem to show that the presence of clay in moderate amounts does not weaken cement mortars.

It was feared that the presence of clay in mortars exposed to the weather might tend to make them absorb moisture and become disin-

tegrated. To ascertain whether this would be so, sets of briquettes were made, one set of Portland cement and sand only, the other containing also different amounts of clay. They were allowed to harden in water for a week, and were then exposed on the roof of the office building for two and one-half years, when they were broken. All of the briquettes appeared to be in perfectly good condition, with sharp, hard edges. Their average tensile strengths in pounds per square inch are shown in the following table :

TABLE No. 19.

Portland cement 1 ;	Sand 2		402
"	"	Clay 0.5	262
"	"	" 1.0	256
"	"	" 1.5	182
"	"	" 2.0	178

The mortars with clay show a very fair degree of strength, and the tests confirm the belief that the presence of clay works little, if any, harm. Tests of mortars made with lime and clay also gave favorable results. Such mortars would stand up in water. The subject is worthy of further investigation.

Experiment No. 14.

Occasionally, for stopping leaks through joints in the sewers, it was found convenient to use cement mixed with melted tallow. The tallow congealed at once and held the water while the joint was being calked. Briquettes made of melted tallow mixed with Portland cement and sand, equal parts, acquired, in one week, a tensile strength of about 40 pounds to the inch. After a month, six months and a year, they were little, if any, stronger. It was thought that possibly the ammonia in the sewage might gradually saponify and dissolve out the grease, leaving the mortar to harden by itself. Briquettes of cement and tallow were kept in water to which a little ammonia was added from time to time. After a year or two the briquettes had swelled to about double their former size, but the cement had acquired no strength.

Experiment No. 15.

Having occasion to build with concrete a large monolithic structure in which a flat wall would be subjected to transverse stress, it was con-

sidered necessary to make experiments to find the comparative resistance to such stress, of concrete made with different cements and with different proportions of sand and stone.

The cements used in the tests were an English Portland and a Rosendale, both good of their respective kinds. Medium coarse pit sand was used, and screened pebbles about an inch or less in diameter. The beams were 10 inches square and 6 feet or less long. They were made in plank moulds resting on the bottom of a gravel pit about 4 feet deep. After the concrete had hardened sufficiently, the moulds were removed, and the undisturbed beams buried in the pit and left for six months exposed to the weather. They were then dug out and broken, with the results given in the table. The total breaking loads are given, including one-half of the weights of the beams, which averaged about 150 pounds per cubic foot. The constant, c, is obtained for the formula—

$$w = \frac{d^2 \times b}{l} \times c, \text{ in which } \begin{cases} w = \text{center breaking load in pounds.} \\ d = \text{depth of beam in inches.} \\ b = \text{breadth of beam in inches.} \\ l = \text{distance between supports in feet.} \\ c = \text{a constant.} \end{cases}$$

Since c has an average value, and there were generally more beams of one length than of the other, the value of c as given does not exactly correspond with either load in the table.

TABLE No. 20.

Proportion of Materials.			Average Center Breaking Weight in pounds.		Average Modulus of Rupture in pounds.	Average Value of c in pounds.
Cement.	Sand.	Stone.	Dist. bet. Supports, 2′ 4½″	Dist. bet. Supports, 5′.		
Rosendale 1...	2	5	1782	690	67	3.7
" 1...	3	7	Beams broke	in handling.		
Portland 1....	3	7	3926	1995	176	9.8
" 1....	4	9	3648	....	146	8.1
" 1....	6	11	2822	1190	112	6.2

The table shows that concrete has a rather low modulus, especially when made of Rosendale cement. When transverse stress is to be opposed it is very important to give ample time for the concrete to harden.

Experiment No. 16.

Many of the main drainage sewers were either built or lined with concrete, which was always smoothly plastered with a coat of mortar. It was important that this surface coat should be especially adapted to resist abrasion. This experiment was made to ascertain the best mixture for the purpose. Different mortars were formed into blocks 1½ inches square, and, after hardening under water for 8 months, were ground down upon a grindstone. The blocks were pressed upon the stone with a fixed pressure of about 20 pounds. A counter was attached to the machine, and the number of revolutions required to grind off 0.1 inch of each block was noted. The cements used in the test blocks were a rather coarse English Portland and a fair Rosendale.

The curves (Plate V) show the results obtained. In making these curves the resistance to abrasion opposed by the Portland cement mortar in the proportion of 1 part cement and 2 parts sand is assumed to be 100, and the resistances of other mortars is compared with it. The effect of the grinding upon the test blocks is noted on the curves, and explains the somewhat striking results.

It appears that cements oppose the greatest resistance to abrasion when combined with the largest amount of sand which they can just bind so firmly that it will grind off and not be pulled out. A little less or a little more of sand may greatly lessen the resistance. For any given cement the proper amount of sand would, probably, have to be ascertained by experiment.

Experiment No. 17.

It is a prevalent belief among masons that cement, even when it contains no free lime, and does not check, expands considerably after setting. It is stated that brick fronts laid with cement mortar (especially of Portland cement) have been known to bulge, and even rise, owing to expansion in the mortar. Experiments were made to ascertain what truth there was in this belief. Several dozens of glass lamp chimneys were filled with mortars made of various brands of American and

Portland cements, both neat and with different admixtures of sand. The chimneys were immersed in water, and, without exception, began to crack within three days. New cracks appeared during the following ten days, after which time hardly a square inch of glass remained which did not show signs of fracture. This showed that the cement certainly expanded, though very slowly, and that the expansion continued for about 2 weeks. None of the cracks opened appreciably, however, so that the *amount* of expansion, which was evidently slight, could not thus be even approximately determined.

A number of 10-inch cubes were then made of similar mortars, with small copper tacks inserted in the centers of all the sides. Some of these cubes were kept in the air, and others immersed in water, and the sizes of all of them were measured frequently by callipers during 6 months. The increase in size did not in any case exceed .01 inch, and may have been less. This indicated that, while cement mortars do expand, the increase in bulk in any dimension does not exceed .001 part of that dimension, and is too slight to be of consequence. In the case of the walls before referred to, supposing them to have been 80 feet high, with five ¼-inch joints to each foot, the total height of mortar would have been 100 inches, and the extreme expansion of the whole could only have been .1 inch. It is probable that the apparent rise was merely a difference in elevation caused by settlements of partition or side walls laid with weaker and compressible mortar.

Experiment No. 18.

It having been reported that cement mortars in contact with wood had sometimes been found to be disintegrated, as if they might have been affected by the wood acids, this experiment was made to see if any such effect could be detected. About a dozen boxes were made, each formed of five different kinds of wood, viz., oak, hard pine, white pine, spruce and ash. The boxes were filled with different cement mortars, and were some of them submerged in fresh and others in salt water. Briquettes were also made of cements mixed with different kinds of sawdust. At the end of a year no effect upon the cements could anywhere be detected.

Experiment No. 19.

Engineers are accustomed to insist on cement mortars being used before they have begun to set, and on their being undisturbed after

that process has begun. With cements which set quickly workmen are tempted to retemper the mortar after it has begun to stiffen. Some experiments were made on mortars which were undisturbed after first setting, and others which were retempered from time to time. Unfortunately all of the conditions of these tests were not accurately recorded, and the results are not considered trustworthy. The following series of tests, which represents an extreme case not met with in actual practice, may be of interest.

A mortar made of one part of Portland cement and two parts of sand was allowed to harden for a week. It was then pulverized, retempered and made into briquettes. These subsequently acquired the following tensile strength in pounds per square inch :

1 week	7
1 month	13
6 months	49
2 years	93

Under the circumstances it is somewhat surprising that the mortar developed as much strength as it did. Good tests to elucidate this subject are much needed.

Experiment No. 20.

A brand of "Selenitic" cement was offered for use on the work, and was said to possess great merits. It was made by treating an ordinary American cement by a patented process. It was tested by comparing it with an untreated sample of the same cement of which it was made. The following are the results of the tests :

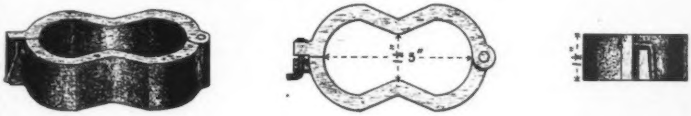
TABLE No. 21.

Mixture.	Kind of Cement.	1 Day.	1 Week.	1 Month.	6 Months.	1 Year.
Neat	Untreated	124	135	140	164	186
Cement,	Selenitic	149	168	171	282	273
Cement, 1,	Untreated	....	121	176	296	316
Sand, 1.5,	Selenitic	....	120	158	276	356
Cement, 1,	Untreated	....	92	154	259	305
Sand, 2,	Selenitic	....	103	133	226	276
Cement, 1,	Untreated.....	....	38	87	158	168
Sand, 4,	Selenitic	....	49	97	167	164

The breakings are somewhat irregular, but seem to show that this cement was made somewhat stronger by the selenitic process of treatment when tested neat, but was little, if at all, improved for use as a mortar; not enough, certainly, to compensate for the higher cost.

BRASS MOULD.

FIG. 1.



BRIQUETTE.

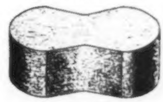


FIG. 2.

PAT OF CEMENT
TESTED FOR CHECK CRACKS.

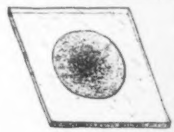


FIG. 4.

TUBE AND BOX
FOR WEIGHING CEMENT.

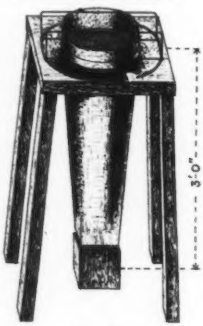
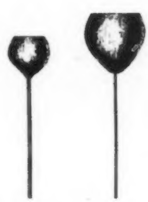


FIG. 3.



LIGHT & HEAVY WIRES.

FIG. 5.

PAN FOR KEEPING BRIQUETTES.

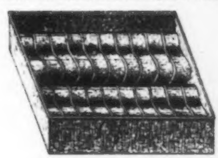
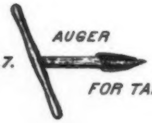


FIG. 6.

AUGER

FIG. 7.



SCOOP

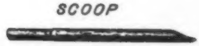


FIG. 8.

FOR TAKING SAMPLES FROM BARRELS.

BARREL OF CEMENT
60 PER CENT FINE

FIG. 9.

BARREL OF CEMENT
90 PER CENT FINE

FIG. 10.

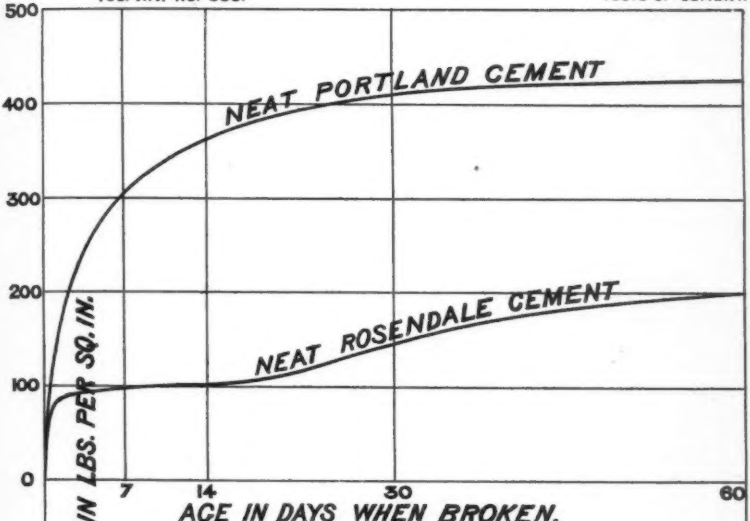

500
400
300
200
100
0
NEAT PORTLAND CEMENT
NEAT ROSENDALE CEMENT
TENSILE STRENGTH IN LBS. PER SQ. IN.
7
14
30
60
AGE IN DAYS WHEN BROKEN.

FIG. 1.

FIG. 2.

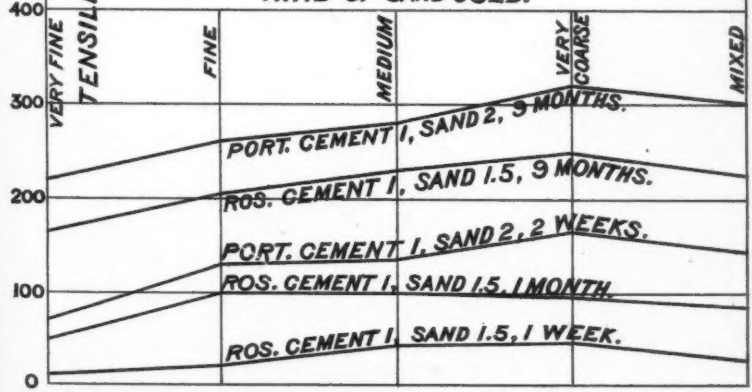

KIND OF SAND USED.
400
300
200
100
0
VERY FINE
FINE
MEDIUM
VERY COARSE
MIXED
PORT. CEMENT 1, SAND 2, 9 MONTHS.
ROS. CEMENT 1, SAND 1.5, 9 MONTHS.
PORT. CEMENT 1, SAND 2, 2 WEEKS.
ROS. CEMENT 1, SAND 1.5, 1 MONTH.
ROS. CEMENT 1, SAND 1.5, 1 WEEK.

PLATE IV.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XIV. NO. 300.

CLARKE ON
TESTS OF CEMENT.

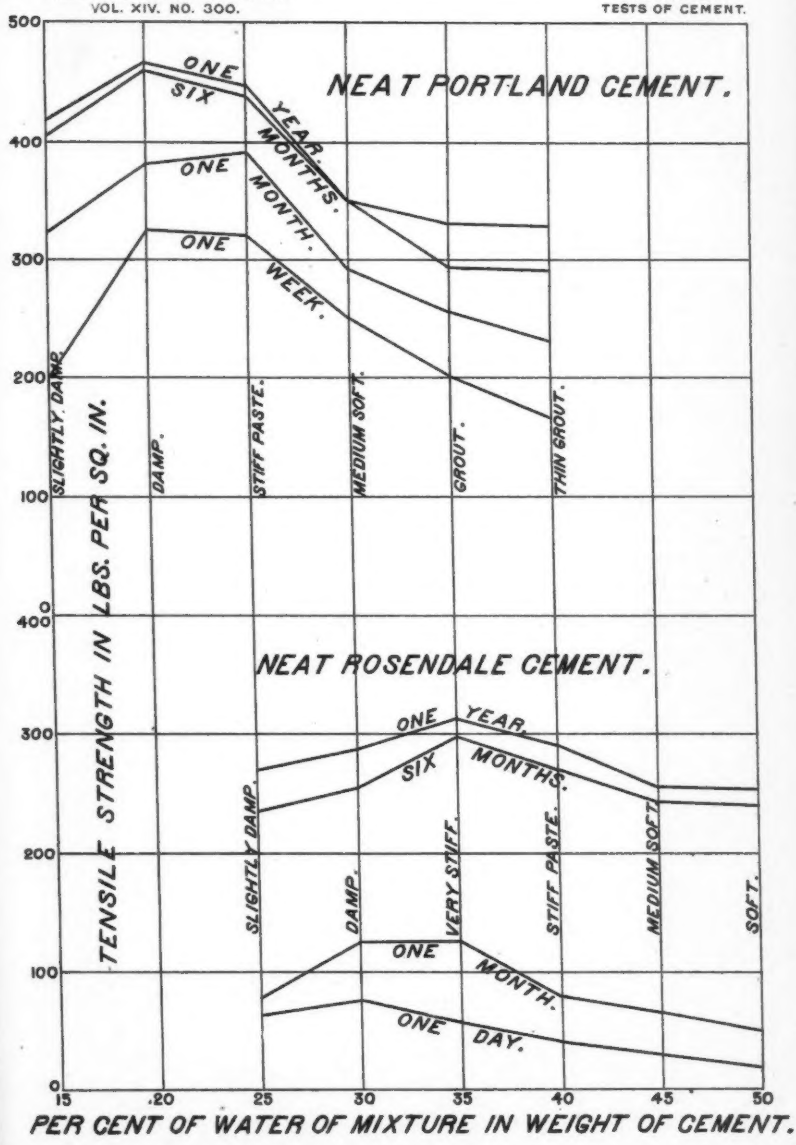
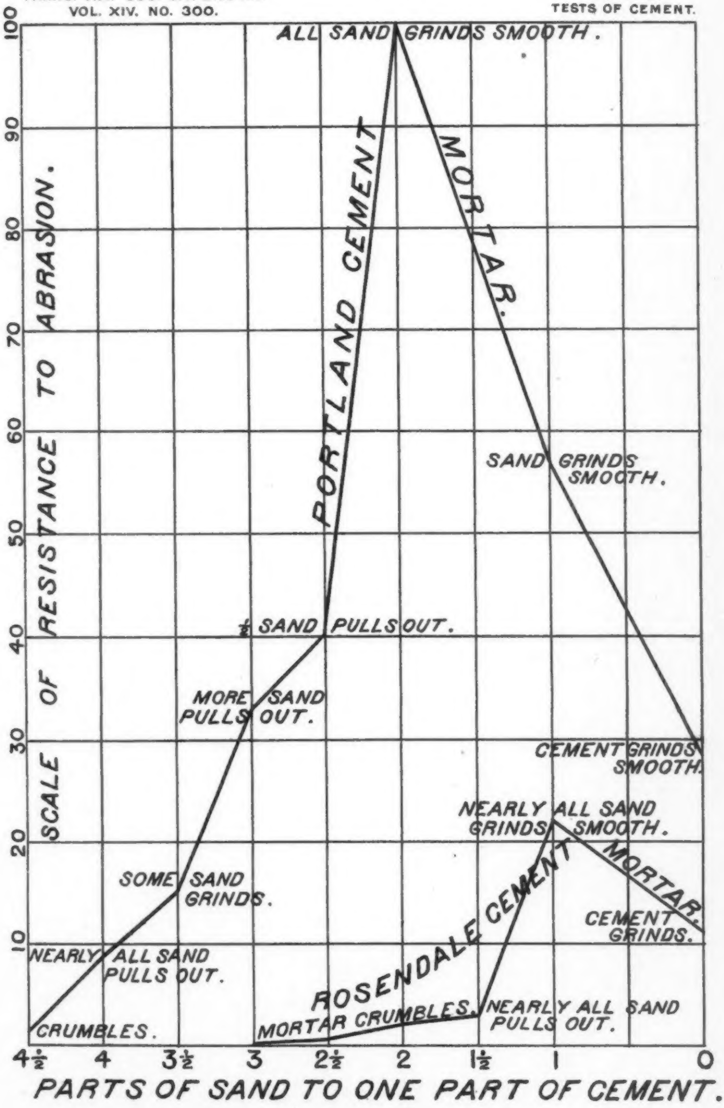


PLATE V.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XIV. NO. 300.

CLARKE ON
TESTS OF CEMENT.



AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

301.
(Vol. XIV.—April, 1885.)

CHIMNEY CONSTRUCTION.

THE PACIFIC MILLS CHIMNEY AT LAWRENCE, MASS., DESIGNED BY HIRAM F. MILLS, C. E.—THE MERRIMACK MANUFACTURING COMPANY'S CHIMNEY AT LOWELL, MASS., DESIGNED BY J. T. BAKER, C. E.—THE STATION B CHIMNEY OF THE NEW YORK STEAM COMPANY, DESIGNED BY CHARLES E. EMERY, M. AM. SOC. C. E.—THE CHIMNEYS OF THE CAMBRIA IRON COMPANY, BY GEORGE WEBB, GENERAL AGENT OF THE COMPANY.

THE PACIFIC MILLS CHIMNEY AT LAWRENCE, MASS., U. S. A.

By HIRAM F. MILLS, C. E.

The Pacific Mills chimney designed by me and built under my direction by Capt. B. F. Chadbourne in 1873–4 consists (see Plate VI) of an outside octagonal shell 222 feet high above ground, with a distinct interior shell or core 8 feet 6 inches in diameter inside, extending 1 foot above the top of the outer shell, and 11 feet below the surface of the ground.

NOTE.—These papers have been kindly prepared by the writers at the special request of the Secretary of the Society.

The whole is founded at a depth of 19 feet below the surface of the ground upon a bed of clean, sharp, coarse, mortar sand 35 feet square, which is inclosed by a tight sheet of pine plank piling 3 inches thick, driven 5 feet, and standing one and one-half feet above the bed. This bed of sand is covered with a bed of concrete 1 foot thick, and upon this rests the pyramidal foundation of large stones of amorphous granite laid in cement mortar, in irregular layers, having the top of each roughly leveled by pointing off the bunches. This mass of stone work, 35 feet square at the base, is 7 feet high and 29 feet square at the top, at the level of the bottom of the flue. The brick flue walls are surrounded on three sides by stone walls 6 feet thick, having outside corners clipped for the height of 5 feet, and with walls 5 feet thick for the remaining height of 6 feet.

Upon this stone work and upon two cast-iron girders spanning the flue space resting upon this stone work rises the outer shell of the chimney, octagonal in form, the base stone, 20 inches high, being placed 22 feet 8 inches from outside to outside, above which is paneled brick work 3 feet thick, with vertical sides 18 feet 6 inches high and 21 feet 8 inches from face to face, surrounded by a belt of granite 16 inches thick and 22 feet 4 inches across from side to side. Upon this, with a width of 20 feet, begins the battering shaft, which, with a straight batter for 160 feet, draws in to a width of 12 feet. The batter then changes, and in a height of 10 feet the width becomes 11 feet 8 inches, and in 10 feet more it becomes 11 feet 6 inches, above which the walls are vertical, with the projections at the corners shown in the elevation. These projections, joining by arches, produce a width of 12 feet 8 inches, above which the head enlarges to a width of 13 feet 8 inches, having vertical sides 3 feet 6 inches high.

The walls of the head are 21 inches thick, decreasing at the arches to 8 inches, which continues to 40 feet below the top; then for 60 feet the thickness is 12 inches; for 40 feet it is 16 inches; for 20 feet it is 20 inches; for 18 feet it is 24 inches, and for 12 feet, or down to the granite belt, it is 28 inches.

Within the outer shell and built up with it are four inside buttresses, 2 feet thick for a height of 27 feet above the bottom of the flue, and 1 foot thick for their remaining height of 154 feet. The inside face of the buttresses was built 1 inch from the outside of the flue wall. The head of the outer shell is covered with 16 cast-iron plates $\frac{3}{4}$ inch thick, held

in place by flanges and by 64 copper bolts 2 feet 6 inches to 2 feet 10 inches long and ¾ inch diameter.

The horizontal flue entering the chimney is 7 feet 6 inches wide, and 7 feet 6 inches high inside. Its walls are 16 inches thick for a height of 5 feet, above which they are 12 inches thick. It is covered by cast-iron girders 2 feet 7 inches apart, between which are small girders running lengthwise of the flue, far enough apart to receive one length of bricks, with their ends resting upon the flange at the bottom.

Upon passing through the outer shell the walls of the flue thicken to 2 feet, and support a cast-iron girder, upon which rests nearly one-third of the circumference of the vertical flue.

This girder is kept back from the inside of the flue, that the gases may not come in contact with it. As the flue bends upward the section is enlarged, and the top, covered with cross girders about 9 inches apart, curves with a radius of 5 feet. The bottom of the flue also bends upward, having a radius of curvature of 9 feet 9 inches.

The vertical flue is a cylinder 8 feet 6 inches in diameter inside, and 234 feet high, having walls of the following thickness and height:

20	inches	thick,	20	feet	high.
16	"	"	17	"	"
12	"	"	52	"	"
8	"	"	145	"	"

Six inches below the top of the flue wall was placed a cast-iron disc, covering 7 inches of the thickness of the wall, and projecting outward 8 inches, covering the space between the core and the outer shell, and upon this the wall was topped out with eight pieces of firebrick, about 3 feet 7 inches long, 8 inches wide and 6 inches deep, held in place by copper bolts set in the wall.

The foundation stones were laid in mortar, made of one part Rosendale cement and two parts of sand.

The outer shell was laid in mortar, made of one cask of cement, two casks of lime, and six casks of sand up to the bottom of the 8 inch wall; then with one cask of cement, one cask of lime, and four casks of sand up to the projections, above which the cement was increased to equal in volume the lime paste.

The mortar for the flue walls was made throughout of one cask of lime and two casks of sand.

The stone foundation was laid between September 16th and October

16th, 1873. The brick-work was continued from October 17th till December 5th, when the outer shell was 50 feet above the ground, and the flue carried on to 90 feet above the ground, that it might be used for a part of the boilers.

On March 7th, 1874, boilers, having 452 square feet of grate surface, burning anthracite coal, were connected with the chimney in this condition, with satisfactory results. This use was continued till June 15th.

On June 5th, began to build up brick work of outer shell, having taken down 5 feet of that built in the winter. On June 22d, 1874, began to build up the core from height of 79 feet above the ground, having taken down 11 feet in height of that built in the winter. On September 15th, 1874, finished building the chimney, and began to take the staging down.

All work of construction above ground was from an outside staging.

The approximate weight of the chimney is 2 250 tons,* of which the stone-work weighs 817 tons; the outer shell, with buttresses, 1 088 tons, and the inner shell 345 tons. The number of bricks used was about 550 000.

The chimney is opposite the middle of a line of twenty-eight boilers, and 210 feet distant from them. Of this length 130 feet consists of two flues 7 feet wide and 4 feet high inside, running into one flue 80 feet long and 7 feet 6 inches square, which enters the chimney. The bottom of the flue at the chimney is about level with the grates.

This chimney was designed to serve for boilers having 700 square feet of grate surface, burning about 13 pounds of anthracite coal per square foot of grate surface per hour.

This chimney was struck by lightning on the 28th of June, 1880, fifty-two minutes after noon, when the fires were burning as usual.

Upon making repairs a lightning rod was put up, which consists of a seamless copper tube $1\frac{5}{16}$ inches outside diameter and 1 inch inside diameter, in lengths of 15 feet. The ends were squared and a thread cut in a lathe for $1\frac{1}{2}$ inches. The couplings were 4 inches long, with 3 inches of thread in the interior and $\frac{1}{2}$ inch in length at each end, plain, and tightly fitting the outside of the pipe. In putting up care was taken to have the ends of the pipe firmly in contact.

At the top are 7 points from a ball 4 inches in diameter, the central

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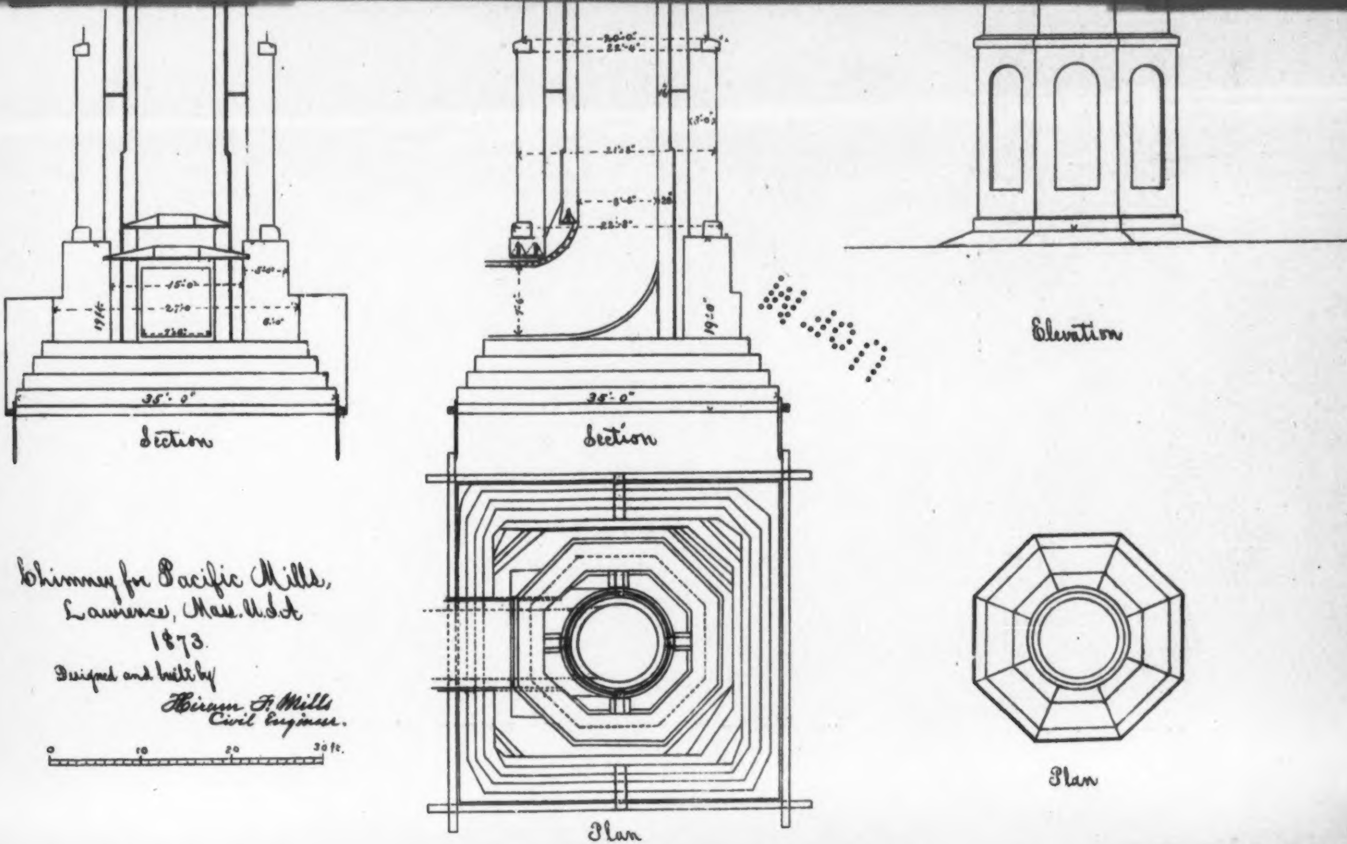
* Gross tons, of 2 240 pounds avoirdupois.


Section
35' 0"
19 1/4
15' 0"
27' 0"
7' 6"
8' 0"
6' 0"
Section
35' 0"
7' 6"
19' 0"
20' 0"
22' 4"
13' 0"
21' 8"
8' 6"
22' 8"
Elevation
Plan
Plan
Chimney for Pacific Mills,
Lawrence, Mass. U.S.A.
1873.
Designed and built by
Hiram F. Mills
Civil Engineer.
0
10
20
30 ft.

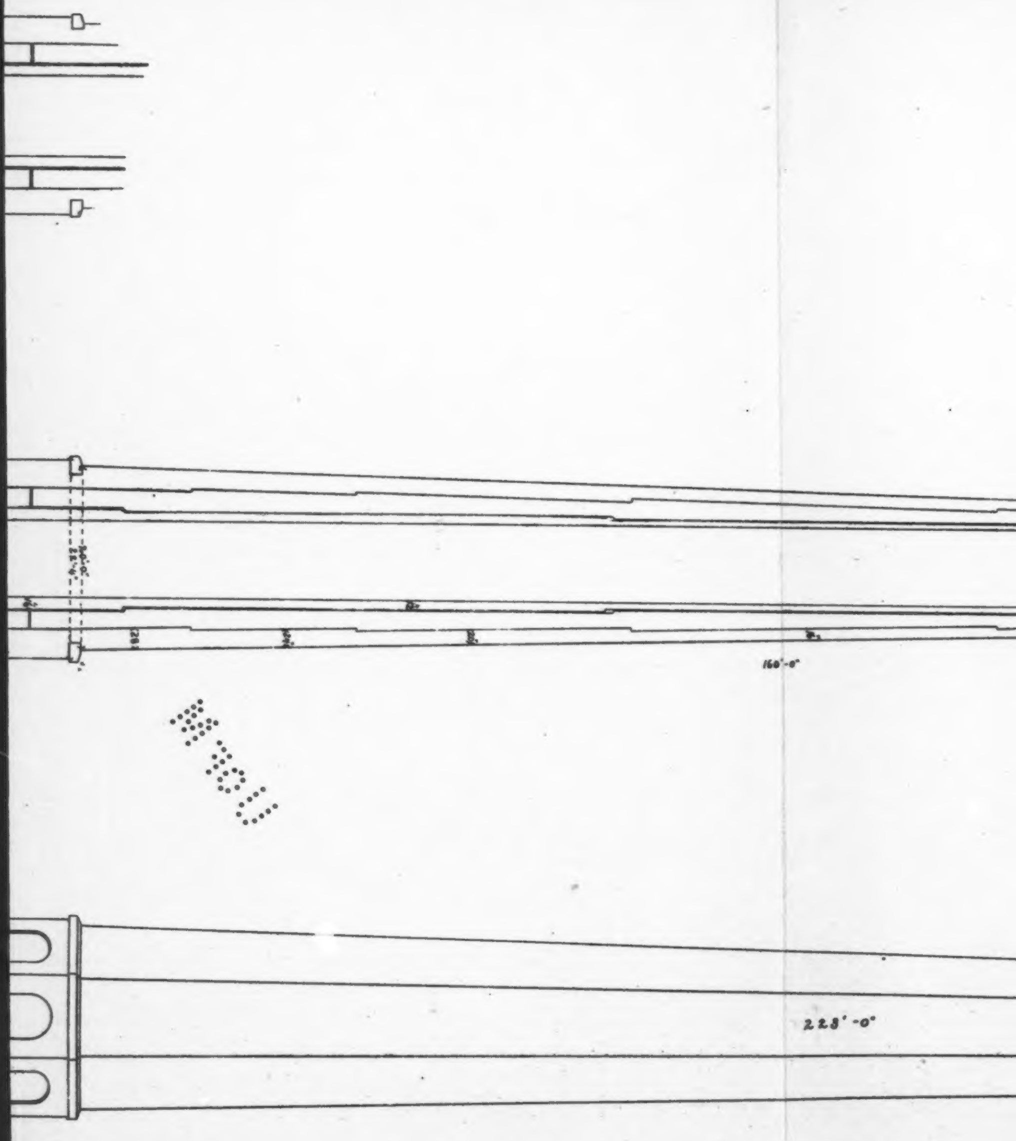
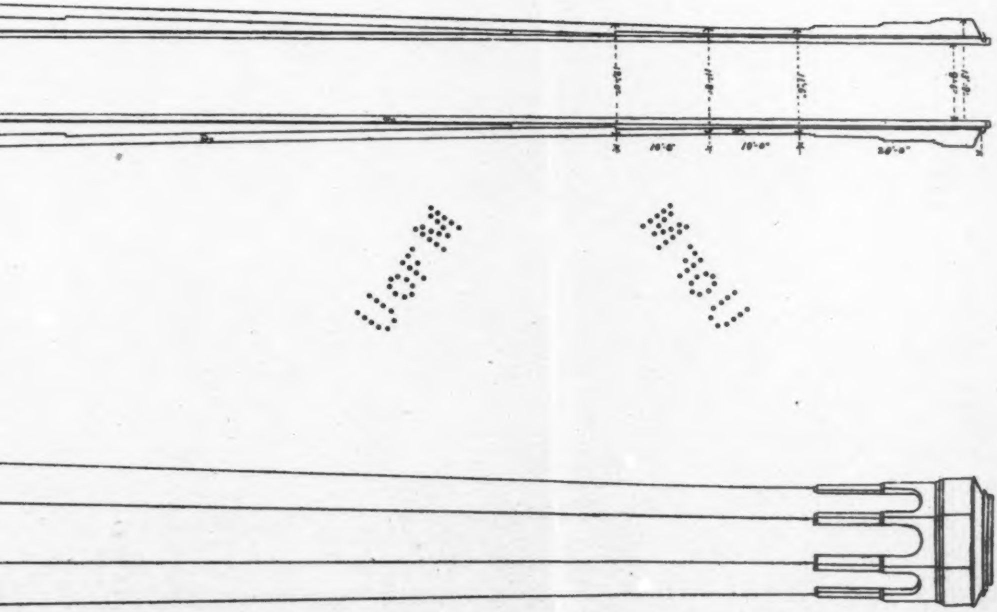

160'-0"
228'-0"

PLATE VI.
TRANS. AM. SOC. CIV. ENG'RS
VOL. XIV NO. 301.
CHIMNEY CONSTRUCTION.



point being 2 feet long, the others 1 foot long. The top of the central point is 8 feet 6 inches above the iron cap which the pipe goes through. Inside of the upper pipe, and extending about 5 feet above the iron cap, is a 1-inch iron rod, 8 feet long, to stiffen the projecting pipe. The pipe is buried in brick-work for 3 feet through the head of the chimney, and is elsewhere held by brass castings $\frac{3}{8}$ inch thick, 4 inches wide, projecting out 2 inches, and running back and hooking down over the back side of a brick $\frac{1}{4}$ inch, being there 2 inches wide and $\frac{1}{8}$ inch thick. These were set in the middle of each pipe and below each coupling. One expansion joint was put in at mid-height.

At the bottom, the pipe, filled with a copper plug, was screwed 2 inches into a copper cylinder 4 inches long and about 4 inches in diameter, which was screwed into a 4-inch cast-iron pipe $\frac{5}{8}$ inch thick, which stood out of ground about 5 inches and extended vertically below ground about 5 feet, and then inclined, extended 60 feet, entering the canal about 7 feet below the surface of the water.

THE MERRIMACK MANUFACTURING COMPANY'S CHIMNEY, AT LOWELL, MASS.

Designed by J. T. Baker, C. E.

The Merrimack Manufacturing Company's chimney, built by Staples Bros., under the direction of J. T. Baker, between May 22d and October 23d, 1882 (see Plates VII and VIII), is founded on a ledge of quartzose sandstone. The top of the ledge on the northwest side of the chimney is 4 feet below the surface of the ground, and about 10 feet below the surface on the southeast side. The top of the ledge was roughly broken off to bring it, by stepping, to approximately horizontal beds; it was then leveled up to the highest point with stone, laid in Portland cement, without sand. The sub-foundation was then built, 30 feet in diameter, to a height of 3 inches above the ground, with large granite blockstone, laid rough as it came from the quarry, having parallel and exceptionally straight beds and builds. On this was set the underpinning of granite, 2 feet 6 inches rise and 18 inches wide, having a wash 6 inches wide cut on the top. The underpinning was in 18 pieces, forming in plan a regular polygon of 18 sides, 29 feet across; inside of and up to the top of the underpinning is filled in with large granite

blockstone, similar to those in the lower part of the foundation. The underpinning is set in clear Portland cement; the remainder of the foundation (above the leveling up) is laid in mortar made of Newark cement and sand, in equal parts by measure. The foundation was commenced on May 22d and finished June 17th. At the top of the underpinning the brick-work starts, consisting of 3 cylinders; the outside one, 28 feet in diameter outside and 24 inches thick, and the middle one, 18 feet in diameter and 8 inches thick, being tied by radial walls, with buttresses inside the middle cylinder, separated from the core by a 1-inch space. The buttresses are 12 inches thick for 130 feet in height, and 8 inches thick for the remaining height of 150 feet. The inside cylinder or core is 12 feet inside diameter and 16 inches thick. On one side of the chimney is a door and arched passageway, 4 feet wide and 7 feet 6 inches high, the bottom being at the top of the underpinning, giving access to the chimney flue. The middle cylinder is carried up vertically to a height of 75 feet 6 inches. The outside ring, battering $\frac{42}{100}$ of an inch per foot to a height of 100 feet, reduces the space between the two to $4\frac{1}{2}$ inches at the height of $75\frac{1}{2}$ feet above the underpinning, where the space is headed over, binding the two cylinders into one $36\frac{1}{2}$ inches thick, reducing to $26\frac{1}{2}$ inches thick at the 100-foot elevation, where the batter changes to $\frac{20}{100}$ of an inch per foot. For a further height of 60 feet the wall is 20 inches thick; for 70 feet additional the wall is 16 inches thick, and for a further height of 34 feet, to the enlargement for the head, the thickness is 12 inches. At the commencement of the head the wall is set off with a 3-inch projection on the outside and 1-inch on the inside, making a 16-inch wall for a height of $12\frac{3}{4}$ inches, then a further set off of 3 inches for a height of $17\frac{7}{8}$ inches, then stepped in 3 inches, above which the brick-work is stepped out, forming a curve with a radius of 20 feet for a height of 6 feet $6\frac{5}{8}$ inches, where the iron cap commences. The height of the cap is 6 feet 11 inches and $\frac{5}{8}$ of an inch in thickness, covering the top, and returning down 9 inches on the inside of the flue. The cap is built up in sections and is bolted together, the flanges being built into the wall, which is built up to the top inside the cap, the core being stopped 6 inches below the cap to allow it to expand freely. The core is uniformly 12 feet inside diameter to the top, the first 100 feet in height being 16 inches thick; for a further height of 60 feet, 12 inches thick; for 90 feet more, 8 inches thick, and for the last $29\frac{1}{2}$ feet, 4 inches thick; it is entirely separate from the outside, excepting about the doorway and

openings for the flues. At a height of 23¼ feet above the underpinning are two openings, 12 feet high and 5 feet wide (arched top and bottom), for the admission of the wrought-iron flues, the center lines in horizontal plane forming an angle of 135 degrees.

The foundation	was	commenced	May		22d, 1882.
"	"	" finished	June		17th.
" brick-work	"	commenced	"		24th.
"	"	" up 100 feet	August		5th.
"	"	" " 200	"	"	25th.
"	"	" " 270	"	September	13th, ready for cap.
"	"	" finished	October		23d, 1882.

There was a delay of from three to four weeks, caused by the cap not being ready; the outside staging was all down before the brick-work was finished, the finishing being done from the inside staging. There were but two and one-half stormy days from the time the brick-work was commenced until it was finished, and two of these occurred while waiting for the cap.

The sub-foundation contains 6 875 cubic feet; weight =	1 031 250	pounds
The shaft (including core, 255 458 bricks) contains 1 101 000 bricks ; weight	5 734 375	"
The cap weighs	18 600	"
Total	6 784 225	"

or 3 392 tons 2 cwt. The brick were ordinary hard-burned, of a dark red color, and common size and shape, being about 8 in. × 4 in. × 2¼ in. The core was laid in mortar made of one cask of lime to about five casks of sand, the outside shell in mortar made of one cask of lime, one of cement, and eight or nine casks of sand. The sand was not measured, but enough was added so that the mortar would just slip clean from the hoe and trowel when being worked. On the southeast side of the chimney is a ladder extending from the ground to the top of the chimney, where the sides are drawn in and a rod of iron 1¼ inches in diameter fastened between them, which is surmounted by a copper ring having four spurs, the rod which passes through the ring forming a central point, and extending 8 feet above the top of the cap. All the points are polished and tinned, and with the ladder form a lightning conductor.

The sides of the ladder at the bottom are drawn in, and a $1\frac{1}{4}$-inch round rod welded at each end to a piece $2\frac{1}{2}$ in. $\times$ $\frac{3}{8}$ in. is fastened between them, one end of the rod being bent so as to be in contact for a length of about 6 feet with a 16 inch water pipe, the faces in contact being polished, and the connection made by soldering the rod firmly to the pipe. The sides of the ladder are of $2\frac{1}{2}$-in. $\times$ $\frac{3}{8}$-in. wrought iron, the joints being secured by a splicing piece of the same size as the sides, and 14 inches long; the surfaces in contact being polished, and bolted and soldered together, making a continuous connection between the tips and the water pipe. The sides are fastened to the chimney by being bolted to pieces of $2\frac{1}{2}$-in. $\times$ $\frac{3}{8}$-in. iron at intervals of 5 feet, projecting from the chimney 10 inches, and built into the brick-work about 12 inches; the rounds are $\frac{3}{4}$ of an inch in diameter, 16 inches long, and 15 inches between centers. There is also on the opposite side from the ladder a $\frac{3}{4}$-inch galvanized iron wire rope, tipped like the ladder (both being connected with the cap), and at the lower end the wires are untwisted for a length of 4 feet, spread and soldered to the 16-inch water pipe to which the ladder is connected. The base of the chimney is in the boiler house, about midway of its length. There are two flues of wrought iron entering the chimney, one from the southerly side being 5 feet by 6 feet, taking the gases from six sets of boilers. Each set is connected with the main flue by a flue 1 foot by 6 feet, the main flue being 1 foot by 6 feet where the first branch flue joins it, and increasing in size by 6 square feet for each set connected with it. The other main flue is 5 feet by 11 feet where it enters the chimney, being designed to take the gases for 9 sets of boilers, though but 6 sets are now connected. The iron flues run through to the inside of the core, the bottom being curved upward with a curve the radius of which is $10\frac{1}{2}$ feet. The boilers are vertical, in sets or nests consisting of a central one 4 feet in diameter, and 24 feet long, with six others arranged around it in a circle, each of the six being 14 feet long and 42 inches in diameter. Each has 61 tubes of 2 inches diameter. The boilers are rated as 300 horse-power per set. Each set has $103\frac{1}{4}$ square feet of grate surface, making for the 12 sets now in place a total of 1 239 square feet of grate surface, burning 10 to 12 pounds of bituminous coal per square foot per hour. The bottom of the chimney flue is 9 inches above the top of the grates.

PLATE VII
TRANS. AM. SOC. CIV. ENG'RS
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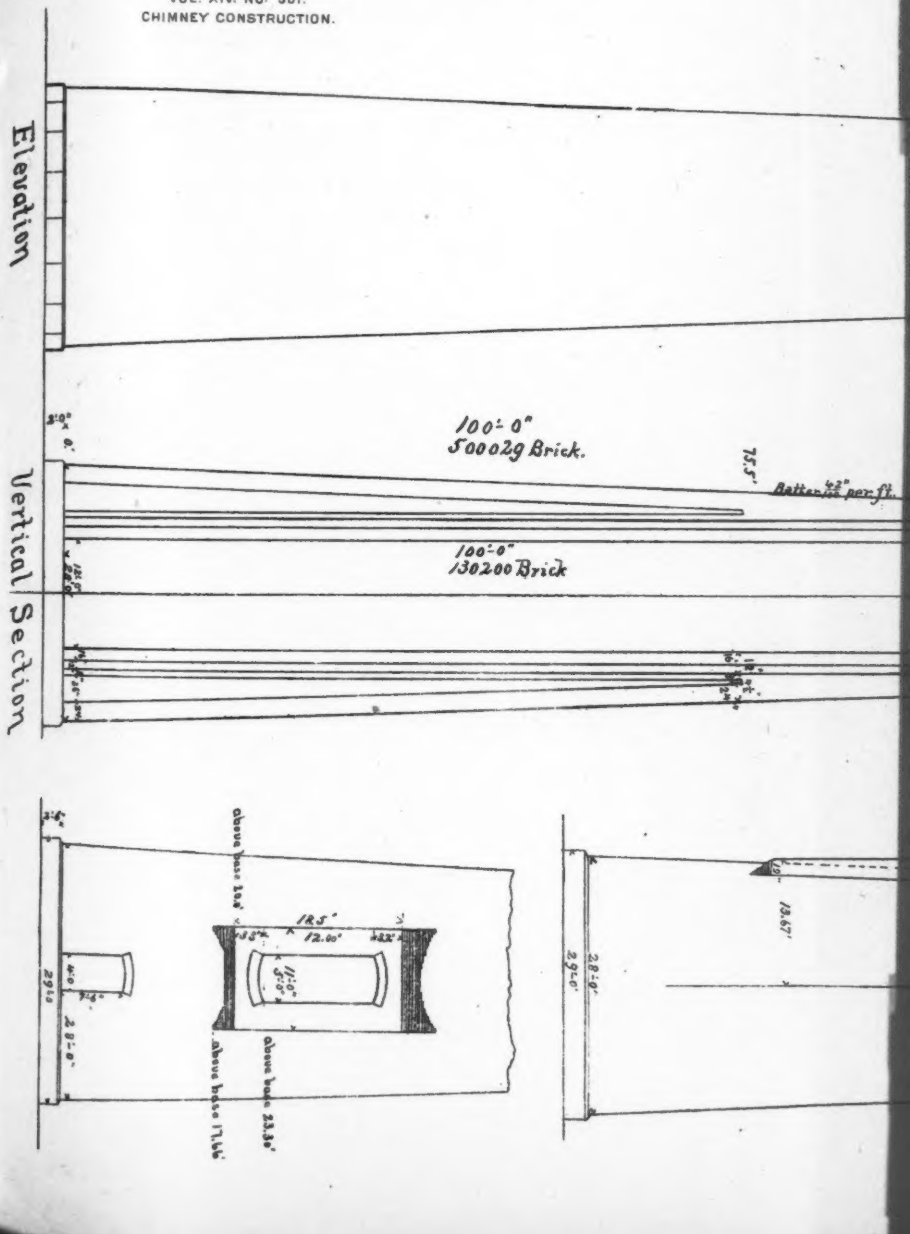
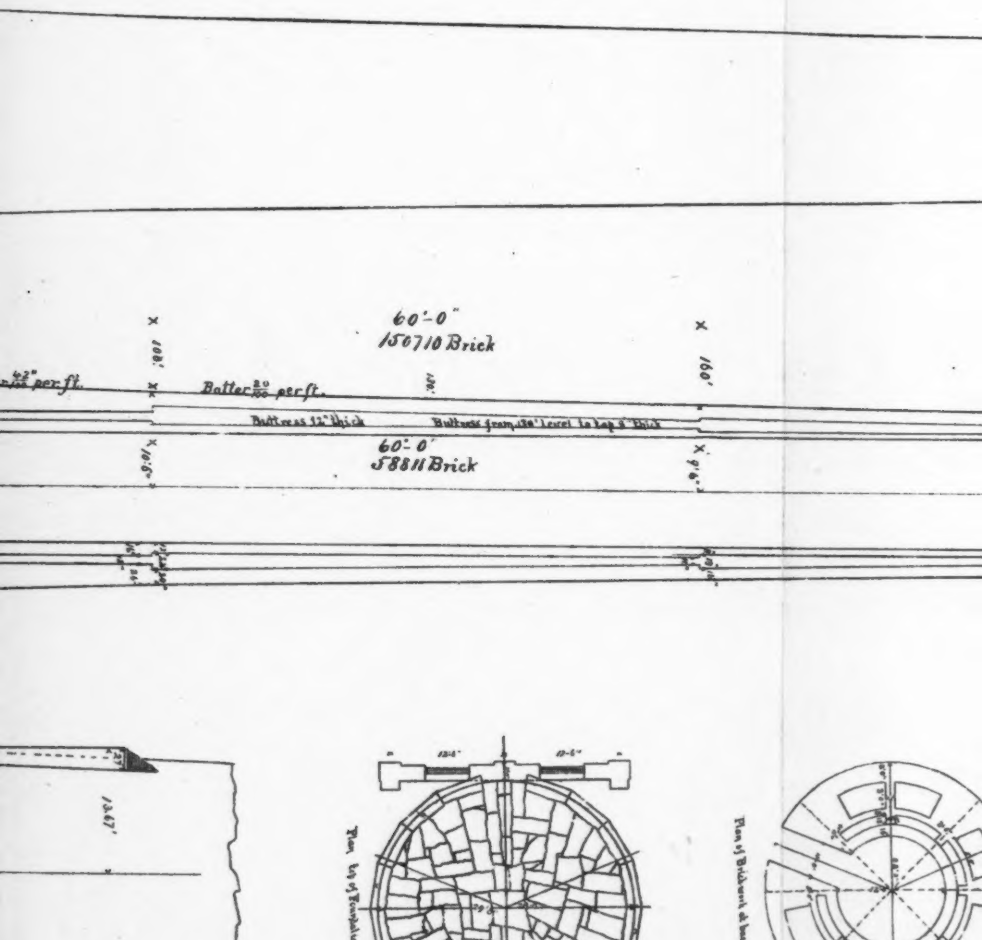
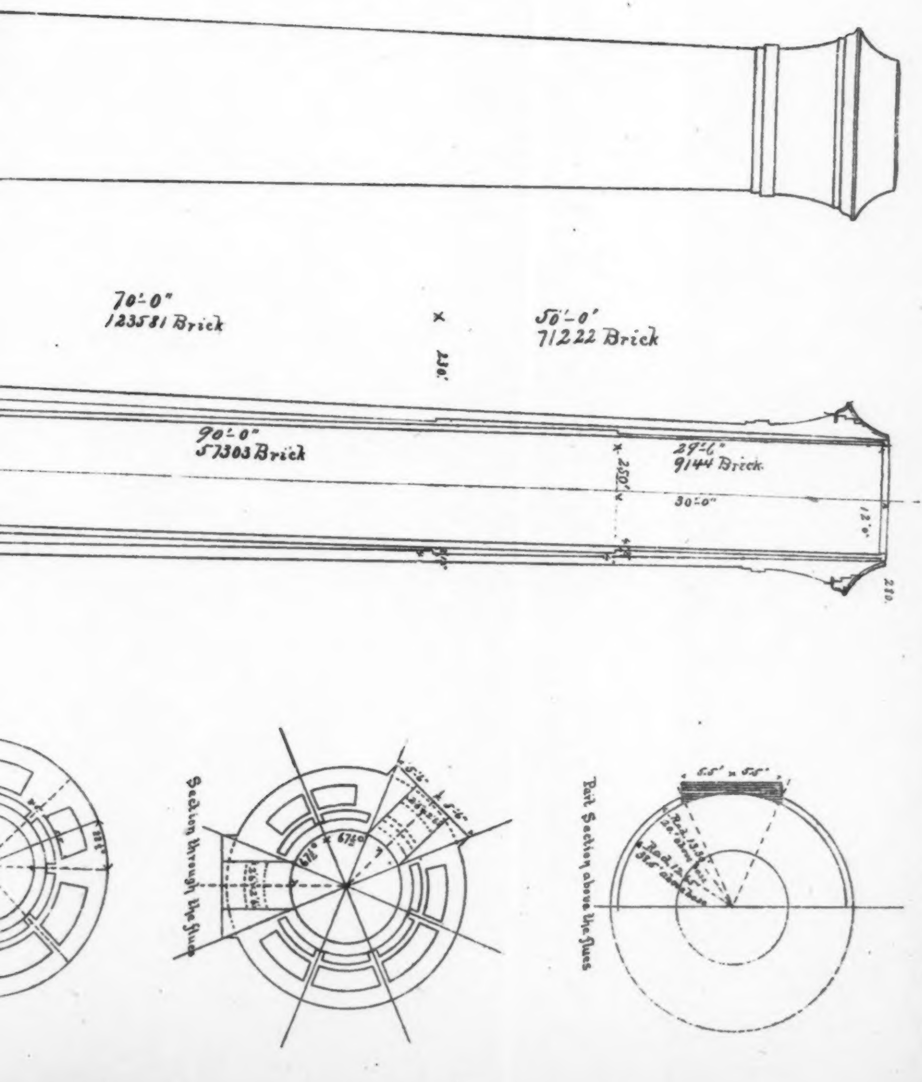
CHIMNEY CONSTRUCTION.



Merrimack Mfg. Co.
Chimney built in 1882





70'-0"
123581 Brick
50'-0'
71222 Brick
230'
90'-0"
57303 Brick
250'
29'-6"
9144 Brick
30'-0"
12'0"
210
Section through the flues
Part Section above the flues

PLATE VIII..
TRANS. AM. SOC. CIV. ENG'RS
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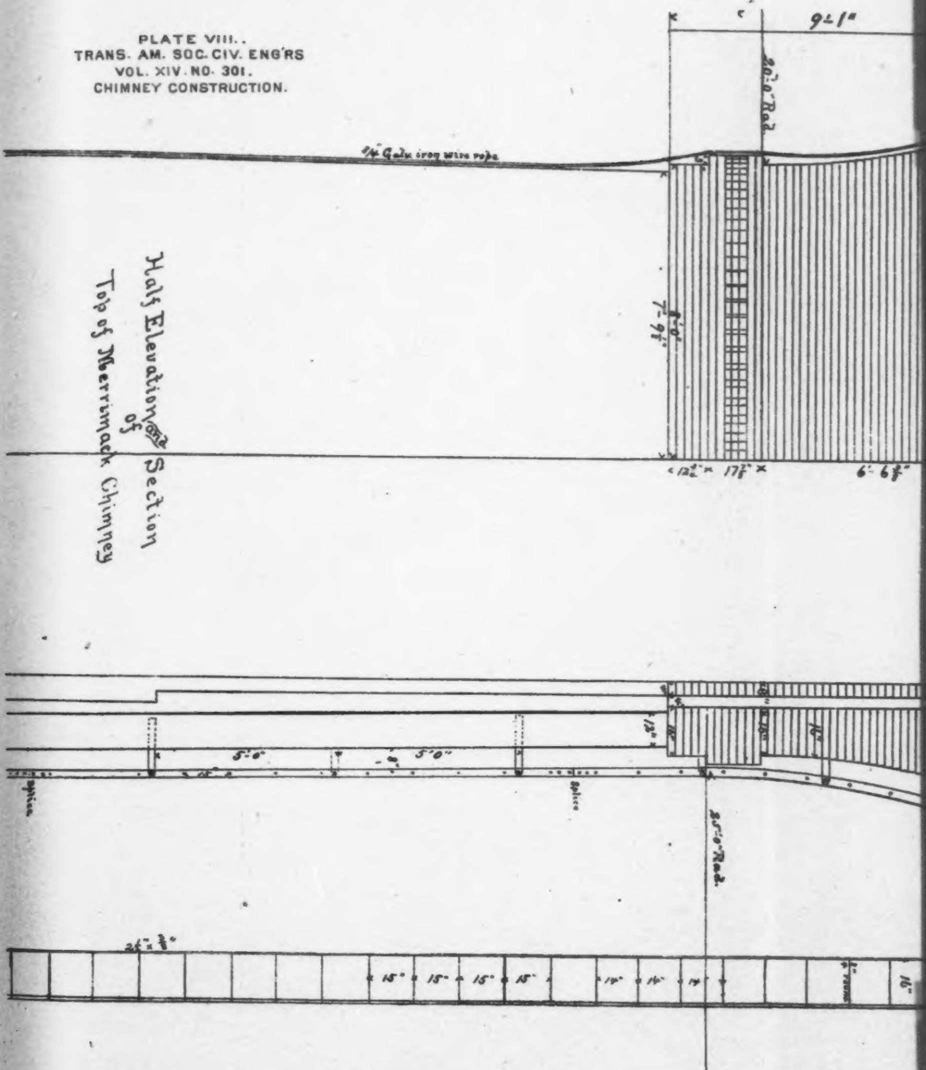
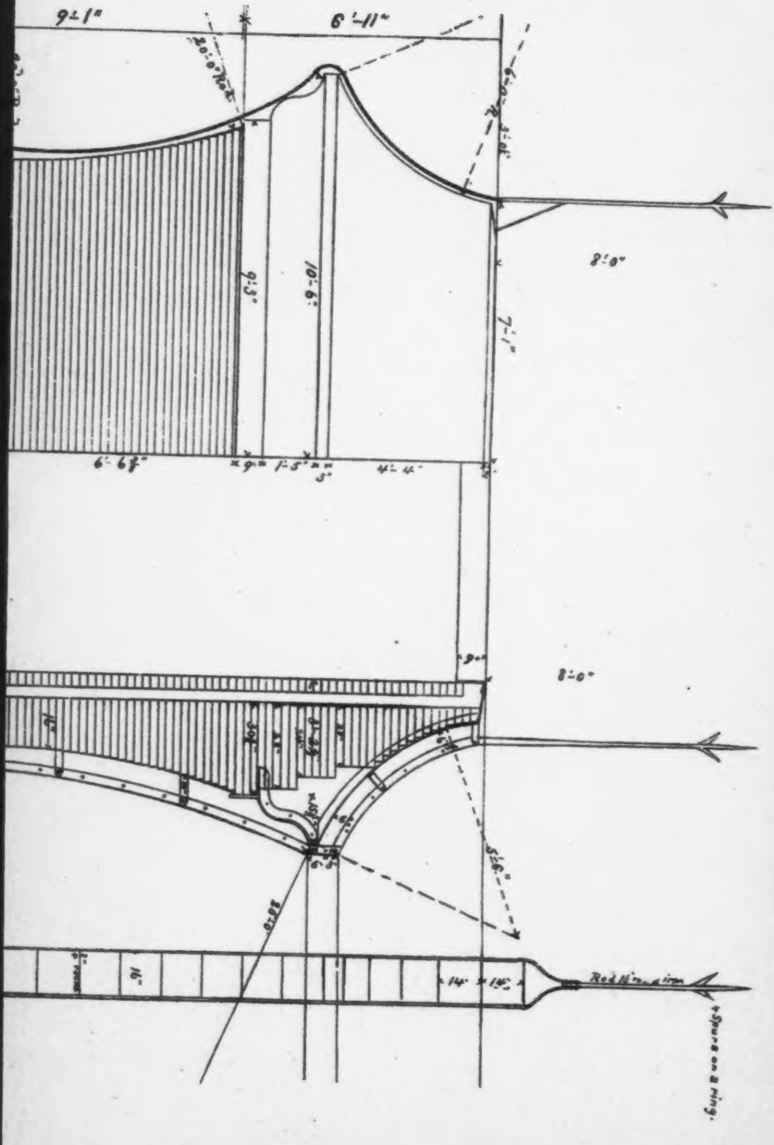
CHIMNEY CONSTRUCTION.



Half Elevation and Section of Top of Merrimack Chimney


9'-1"
6'-11"
8'-0"
7'-1"
10'-6"
9'-3"
4'-4"
8'-0"
5'-6"

Details of the Merrimack Chimney.

Description of chimney	Round.
Lightning conductors	$\frac{3}{4}$-inch galvanized iron wire rope and ladder, both copper tipped.
Cost of conductors in place	$200.
Total height, including foundation	289$\frac{3}{4}$ feet.
Height from ground line to top	282$\frac{3}{4}$ "
Outside measurement at ground	30 "
Inside " " "	Solid.
Outside " " foundation	28 feet.
Inside " " "	12 "
Outside " at top (under head)	15 " 6$\frac{1}{4}$ inches.
Inside " " "	12 "
Average diminution of shaft from ground line,	$\frac{28}{100}$ of an inch per foot.
Proportion of diameter to height	One-tenth ($\frac{1}{10}$).
Weight	3 392 tons 2 cwt.
Number of brick used	1 101 000.
Stone masonry	6 875 cubic feet.
Cast-iron cap	18 600 pounds.
Scaffold used	Both inside and outside.
Cost of scaffold	Not known; about $420.
Cost of chimney complete	$18 500.
For whom constructed	Merrimack Mfg. Company, Lowell, Mass.
When built	Between May 22d and October 23d, 1882.
Time occupied in building	Five months.
Engineer	J. T. Baker.
Builders	Staples Brothers.
Nature of foundation	Sandstone ledge.
Number of flues from boilers	Two.
Horse-power of boilers	3 600.
Kind and shape of brick	Ordinary brick, hard burned, 8" long, 4" wide and 2$\frac{1}{4}$" thick.

THE STATION B CHIMNEY OF THE NEW YORK STEAM CO.

By CHAS. E. EMERY, M. Am. Soc. C. E.

In connection with the plans of the Merrimac and Pacific Mills chimneys, I, at the request of the Secretary, present a brief description of the chimney, and incidentally of the boiler station of the New York Steam Company, constructed under my direction at "Station B" of that company, in Greenwich street, between Cortlandt and Dey streets, New York.

This chimney may be called a "creature of circumstances," from the fact that it was necessary to erect boilers of sixteen thousand horse-power on an irregularly shaped plot 75 feet in width and on the average less than 120 feet deep, and the chimneys were necessarily shaped to suit the space available. To obtain proper floor room the boilers were arranged in four tiers, each tier in a separate story 20 feet high, besides which the plans provide for a fifth story for coal storage and a basement for miscellaneous uses. Each floor is arranged for sixteen boilers of 250 horse-power each, which are placed in two rows to face a central fire room. There are two chimneys, one located between the boilers on each side of the fire room as near the center of the building as the shape of the plot permitted.

Plate IX is a plan view of one story of the building and includes a horizontal section at a lower elevation through the vault under the sidewalk on Greenwich street; *AA* are the chimneys; *BB* the elevators; *YY* vertical steam drums; *DD* steam pipes to street; *EE* bases of columns of the elevated railroad in street; *FF* is the fire room, and *G* a circular staircase. The locations of boilers are numbered from 1 to 16. At the left are shown the floor beams in position, and on the right the side walls and steam drums, *CC*, of some of the boilers are represented.

Figure 2, Plate X, shows on the right a vertical transverse section of the building, with a boiler in position on one floor, and at the left a transverse vertical section of one chimney.

Figure 3, on the same plate, shows a longitudinal section of the same chimney.

The whole capacity of the building not being needed at first, the walls were only carried up to an elevation of 88 feet 8 inches, and a temporary roof applied, so that at present there are available only three

stories for boilers and one above for coal storage. The south chimney has been practically completed. The north one is extended through the temporary roof and covered, but is connected with the other by a sheet-iron casing at the level of the openings, *O O*. There are now in place thirty-five boilers, aggregating 8,750 horse-power.

Customers were first supplied with steam in April, 1882, since which time the steam pressure has been maintained continuously day and night. The coal is brought from the dock in carts and wagons and dumped from the rear street into small cars in the basement of the rear buildings. These cars are run back to the elevators, lifted to the top of the main building, run out on tracks over coal bins and dumped, the coal descending by gravity through chutes in front of each alternate column and flowing out as needed on the several fire room floors close alongside the fronts of the boilers. The ashes pass from the ash pans down chutes in front of intermediate columns to cars in the basement. These cars are hoisted on the elevator to the roof of the rear building, run out on tracks to front of that building, and the ashes dumped into a chute, from which they are loaded into carts on the street below.

The boilers are of the sectional type, manufactured by the Babcock & Wilcox Company.

From lack of room, a well-established rule was necessarily disregarded, and the lower portions of the chimneys, instead of being independent, were made part of the building; the section of each being rectangular and corresponding closely to the floor space occupied by one of the boilers. Within the building the outside of the chimney walls are vertical; the offsets, due to reducing the thickness of walls upward, being inside the flue. Above the roof the inside of flue is parallel, and the walls are decreased on the outside, each offset being marked by a belt of granite blocks, forming a water table. The lining extends only to the roof line, and is put in in sections, supported on the internal offsets. The lower part of each chimney, above the footings, is 32 feet long outside, and 13 feet wide. The flue at the top is 27 feet 10 inches long and 8 feet 4 inches wide. The south chimney is topped out at a height of 220 feet above high water, or 221 feet above its foundation. The top of chimney is, therefore, 201 feet above the grates of the lower tier of boilers, but only 141 feet above the grates of the upper tier of boilers.

The foundations of the walls of the building are at the elevation of mean high water, and the chimney and column foundations 1 foot

below. The foundations are of concrete, laid directly on the sand of the old beach, which formerly extended to this point. The sand was, for the greater part, quite fine, but there were pockets of sharp gravel containing, at some points, small stone. The foundations were below the spring line, and the sand, being thoroughly saturated with water, would flow when disturbed or undermined. The walls of most of the buildings in the vicinity were laid on longitudinal timbers, located at or near the line of high water, and showed no cracks or signs of settlement. The chimney and boiler house were, however, to be exceptionally heavy; so it was thought desirable, before beginning work, to test the bearing power of the sand, preliminary to which a test pit was sunk until the water became troublesome, when an iron tube was started down with a view of detecting any covered mud or other want of homogenity due to the shifting of the river bank. All preliminary work was, however, promptly stopped by the management; the statement of possible difficulties being considered valueless as against the opinion of builders and others that a good foundation could be obtained without piling at that location. The bases of the foundations could not be spread so as to reduce the pressure on the sand below 4 tons per square foot for the finished structure; and, before one-third of this pressure was reached, it became evident that the wet sand was compressible, and limited settlements took place which were not entirely uniform, as the chimney foundation received its full load before that caused by the boilers was received on the foundations of columns and walls. Eventually some narrow vertical cracks appeared, which relieved the strains, apparently without any material injury to the structure.

The concrete foundation under walls of building is 9 feet wide and 2 to 4 feet thick; under the chimney, 22 feet wide and 4 feet thick, and under the two rows of columns, 18½ feet wide and 3 feet thick. The two chimney foundations are joined by a brick invert. Concrete at the elevation of that under the side walls was first extended over the entire area of the building, and an additional layer, 1 foot thick, applied afterward, the surface of which forms the basement floor. The walls are racked out at the bases to a width of 8 feet. The enlarged base of chimney is 20 feet wide. The walls of chimney, just above the footings, are 3 feet thick at the rear, 3 feet 8 inches on the sides, and 5 feet on the front (toward the other chimney). The walls decrease, as shown on plan, to 20 inches thick at the top of chimney. An archway, *A*, is

provided through the base of each chimney, as a means of communication between different parts of the basement. The opening, *B*, is provided to clean the interior of chimney. On each floor and at each side of chimney, at rear of boilers, are provided the openings, *C C C C*, shaped to connect the horizontal flues from boilers, the openings being strengthened by complete blind arches, *d d d d*, above the partial arches at tops of flue openings. The openings, *O O O O*, are designed for the application of economizers in the future, the gases to be brought out of the lower ones and returned to chimney through the upper ones. The upper part of chimney is stayed at *f f f* by iron rods passing through struts of pipe.

A fixed iron ladder is attached to the interior face of chimney, and connected at top with points and at bottom with cable to form a lightning protector. It was designed to make the top of the chimney with a projecting platform and iron reticulated balustrade, as shown by design at upper part of Plate X, in which case the chimney would have been 232 feet above high water. It was hoped that by painting the balustrade prominently it would give the effect of a capital to the shaft without the weight of actual surface projections. For various reasons, however, the top was finished with a granite coping at the elevation of 220 feet above high water, as previously stated; a simple footboard being provided about the chimney, as shown, with an iron handrail secured in coping stones.

Although the chimney appears slender the narrow way, it is supported by the walls to the elevation of openings, *O O*, and above that point it is calculated to have ample weight to resist the overturning moment caused by a wind pressure of 50 pounds per square foot on the area of one flat side.

The writer takes pleasure in acknowledging the valuable services of Mr. H. W. Brinckerhoff, M. Am. Soc. C. E., Assistant Engineer in immediate charge of the work during design and construction, and at a later date of those of Mr. Thos. E. Brown, Jr., M. Am. Soc. C. E., who was associated with Mr. Brinckerhoff.

These designs have accomplished their purpose for the particular conditions encountered; but the necessity of putting the plant on such limited space has largely increased the cost of the work, and caused continual embarrassments in the details of the internal arrangements. The other stations being located where land is less valuable, larger plots have been obtained and different designs throughout can be employed.

DISCUSSION.

Wm. E. Worthen, M. Am. Soc. C. E.—How much coal do you use?

Mr. Emery.—At present about 100 tons per day in the summer and 200 tons in the winter. The station when completed will have a capacity for consuming 700 to 800 tons per day, but there is so much difference between the demand for steam during day and night that it is not probable more than 400 tons per day will be used.

Wm. G. Hamilton, M. Am. Soc. C. E.—How will they get the coal in?

Mr. Emery.—That has been quite a study. The present arrangements will probably answer for a consumption of 300 tons per day. Eventually we will arrange to land coal cars on the dock in New York at night, haul them to the rear of the building, shoot the coal into hoppers, and convey and elevate it in the same manner as grain. We have estimates for apparatus of this kind guaranteed to put in position 1 000 tons per night. We are so near the river that there has been some talk of elevating the coal from a dock opposite and running it back with conveyers on an elevated trestle to the top of the building.

Mr. Worthen.—What sort of grates do you use?

Mr. Emery.—The ordinary grates, usually. We have now a shaking grate that operates very well, and assists considerably in cleaning the fires.

Mr. Worthen.—How often do you clean them?

Mr. Emery.—The fires are cleaned with a hoe once every six hours.

Mr. Worthen.—How much horse-power?

Mr. Emery.—We are now operating about 2 500 horse-power of boilers in the summer and 5 000 in the winter.

Theodore Cooper, M. Am. Soc. C. E.—With the sort of coal you are using I should think it would be better to clean every four hours. I should think that clinkers would form so as to be unmanageable by leaving the fires without cleaning so long.

Mr. Emery.—On shipboard it is customary to clean fires every four hours; but as we change the watch at the station every six hours the firemen are expected to clean each fire once every watch thoroughly with a hoe, and break them up and pick out clinkers as often as may be necessary. The new bar we have seems to give very good results.

Mr. Cooper.—Yes, that grate works very well wherever I have seen it; but they are cleaned every two hours.

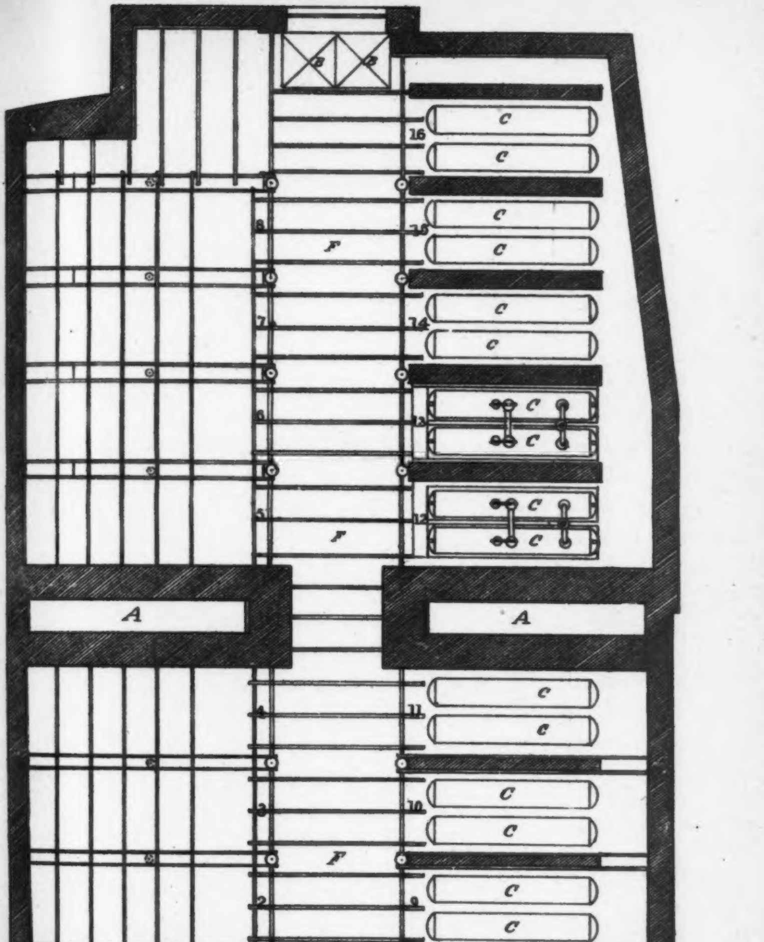


PLATE IX
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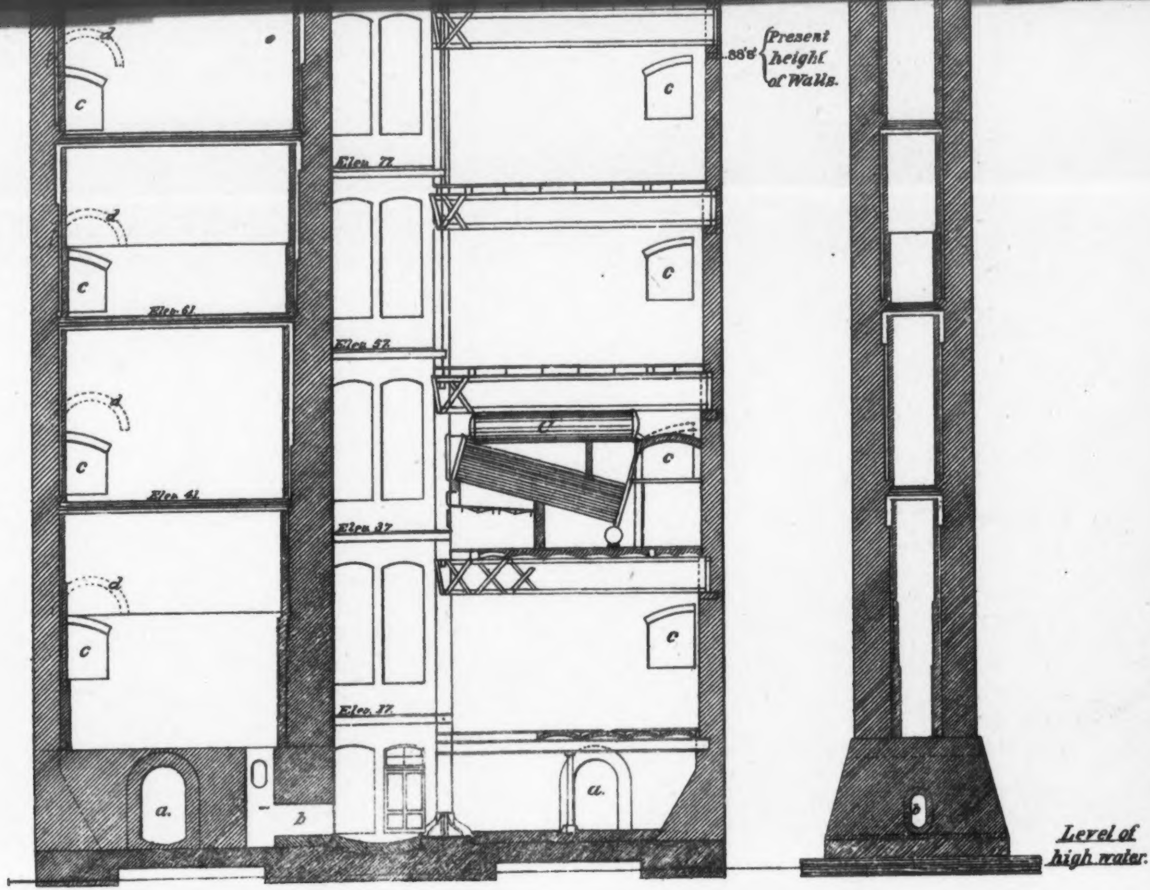
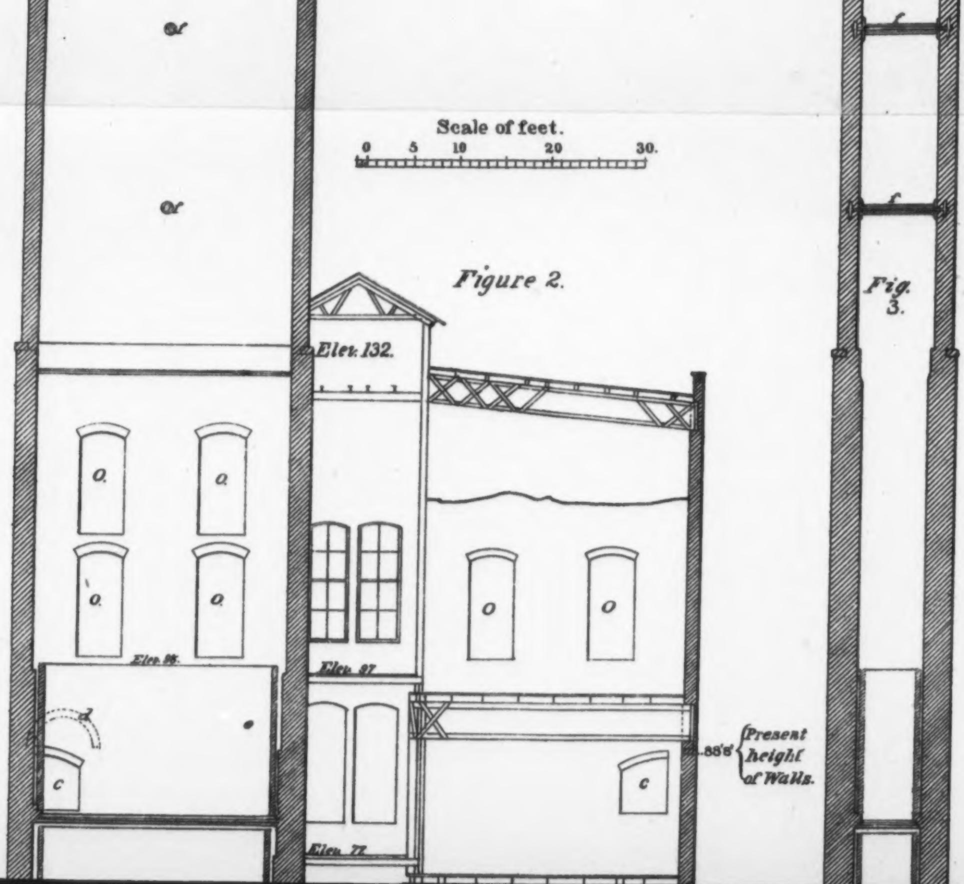
CHIMNEY CONSTRUCTION.



88'8" Present height of Walls.
Elev. 77
Elev. 61
Elev. 57
Elev. 41
Elev. 37
Elev. 17
Level of high water.



Scale of feet.
0 5 10 20 30.
Elev. 132.
Elev. 98.
Elev. 97
Elev. 77
88'8' Present height of Walls.
Fig. 3.

Figure 2.

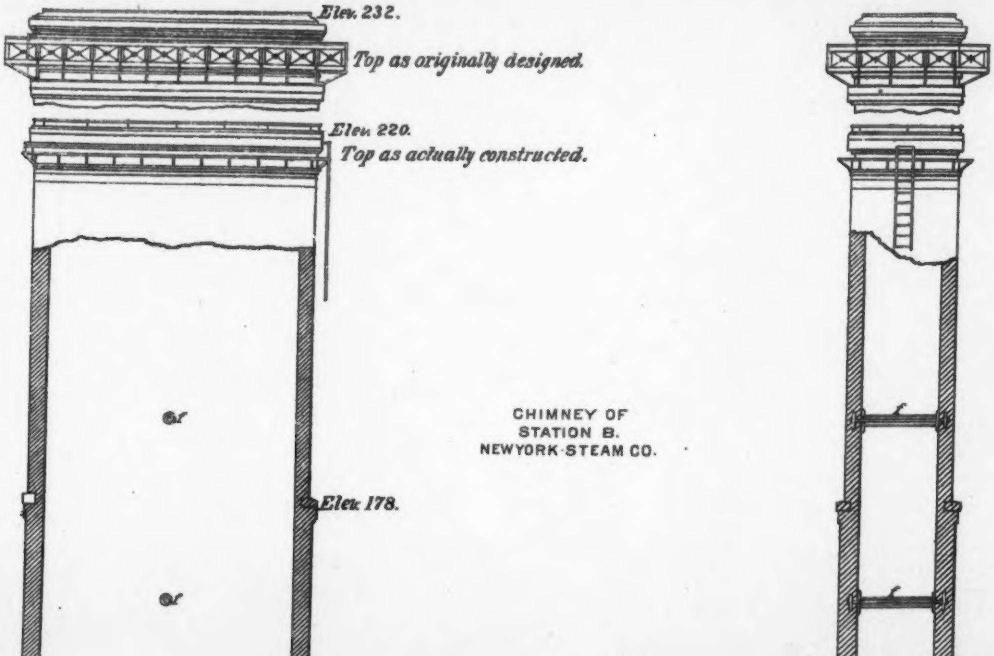


PLATE X.
TRANS. AM. SOC. CIV. ENG'RS
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CHIMNEY CONSTRUCTION.

Mr. EMERY.—I think that would be too often. A shaking grate can be operated every two hours; but with this grate we allow the ashes to accumulate, then partially revolve the grates, cutting out the bottom of the superincumbent mass, and it is desirable to let a considerable thickness of ashes and clinkers accumulate, so as not to waste coal. We find by the use of steam jets that few clinkers are formed.

Mr. HAMILTON.—Have you tried a mixture of soft coal and dust?

Mr. EMERY.—We have tried experiments with dust, both with and without a mixture of soft coal. The results were not advantageous, as compared with our present methods. Very many more boilers were required to obtain the same power, and, as we already fire two of our 250-horse-power boilers with one man, we would be obliged to employ a man for every two boilers added. The dust does not give as high an evaporative efficiency as the smaller coals, with dust excluded; so the losses from this source, together with additional labor, pretty nearly balance the difference in price of coal. Moreover, we must be prepared at all times for a sudden demand for steam, and with dust there is no reserve power.

F. C. PRINDLE, M. Am. Soc. C. E.—Does the pressure vary much with the varying demand for steam?

Mr. EMERY.—Not very much. We maintain 80 pounds pressure, within 5 pounds most of the time. Since April, 1882, the pressure has been down to 60 pounds but two or three times, and then only for a short time.

A. FTELEY, M. Am. Soc. C. E.—Do the boiler flues enter at right angles or with curves?

Mr. EMERY.—They enter the large chimney at right angles. There is no opportunity to make curves. The chimney is so large that this fact does not seem to affect the draft.

Mr. COOPER.—Do you measure the draft?

Mr. EMERY.—We have. We readily get three quarters of an inch of water at the fronts of the boilers.

J. P. DAVIS, M. Am. Soc. C. E.—Is the material common brick?

Mr. EMERY.—Yes, sir.

Mr. COOPER.—How hot do you suppose the gases are in the chimney?

Mr. EMERY.—Occasionally as hot as 460° to 480°; but usually below 400°.

THE "CRINOLINE" CHIMNEYS OF THE CAMBRIA IRON COMPANY AT JOHNSTOWN, PA.

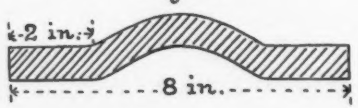
By Mr. George Webb.

These chimneys (Plate XI) are connected to the boiler-house by underground brick conduits, and are intended as "uptakes" for the unused gases. The surplus gases are used for generating steam, and but little is left after passing under the boilers. Sometimes the fires under the boilers must be reinforced with raw coal, in which case the chimneys convey some smoke. The ground is bad, and hence there is a deep foundation of masonry below the surface. From the entrance of the conduit to about 8 feet above the surface, the base of the chimney is hexagonal, of hammered stone, surmounted by a cut-stone coping. Six 3-inch anchor bolts are built into this base and provided with suitable nuts to hold down a base-plate 4 inches thick, and with an upward projecting rim six inches high around a circle 12 feet in diameter. From this base-plate it is 140 feet to the top of the chimney. At the top is a moulded cast-iron plate similar to the base-plate, with the rim projecting downward, 10 feet 2 inches in diameter. The batter is, therefore, 22 inches in 140 feet.

Between these two plates the "crinoline" is constructed. It consists of sixteen vertical lines of ordinary wrought-iron railroad rails, 4-inch base, with the base outward, surrounded by forty-five hoops. The rails may be in sections of any length which will allow of the splice being riveted to a hoop, care being taken to avoid having more than one rail-splice on the same hoop. Well-selected old iron rails with good bases or sound sections of No. 2 or No. 3 rails are as good as any.

The hoops are of wrought iron, rolled from iron $\frac{3}{4}$ inch thick into the section shown in Fig. 1.

Fig. 1.



Each hoop is in two pieces, bent cold to a true segment in a wedge-adjusting bending-machine, which allows any desired delicacy of touch. The piece lies on edge while being bent, the "former" being more readily tried in that way. If bent hot the curve cannot be maintained while cooling.

The two halves of each hoop are spliced on the inside with flat plates, secured with four rivets and one bolt in each end of each section, care being taken that at least three hoops shall intervene solid before another hoop-splice is made between the same verticals. There are 45 hoops, the bottom one being near the base-plate projection, and, therefore, about 12 feet in diameter. The distance in the clear from this hoop to the next one above is 22 inches. The clear distance between each pair of hoops gradually increases from the bottom to the top, the distance in the clear between the top hoop and the next below being 54 inches.

Each hoop is riveted to each rail with two rivets, one in the upper flat space of the hoop and the other on the other flange of the rail in the lower flat space of the hoop.

The iron skeleton thus made is so stable that no scaffolding is used in construction. Two boards across a lower ring will hold a portable forge. A rail section is hauled up, put in place, adjusted and riveted; then others in the same way.

The center opening of the chimney is 8 feet, which is preserved throughout. The bricks fill from this center opening to the inner side of the hoops, special bricks being moulded to fit around the rail heads and thus save time and waste of cutting. To save cutting bricks the masons carried the inside parallel with the outer batter, and when the inside got to 8 feet in the clear, they set back on the inside to an even brick, and then followed the outer batter until the inner diameter reached 8 feet again, and so on. There are about 1 000 bricks average to one foot in height of stack.

Five bricklayers and nine laborers lined the first chimney built in 21 days, the next in 18½ days. They used no scaffolding but two scantlings and a few boards on the inside at convenient intervals, thus leaving a well-hole open the entire height. These were removed from the top downward after completion.

A light iron ladder is riveted to (say) every third hoop, the entire height. The convenience of this for construction, examination and repairs, if needed, is obvious.

The strength of this chimney is in the "crinoline." The bricks are merely for enclosure of the gases. Their mass is so small and the walls are so thin that they are never hot. The "crinoline" of the first chimney was built the entire height before the brick-work was begun. Some heavy storms occurred while it stood thus and it never wavered.

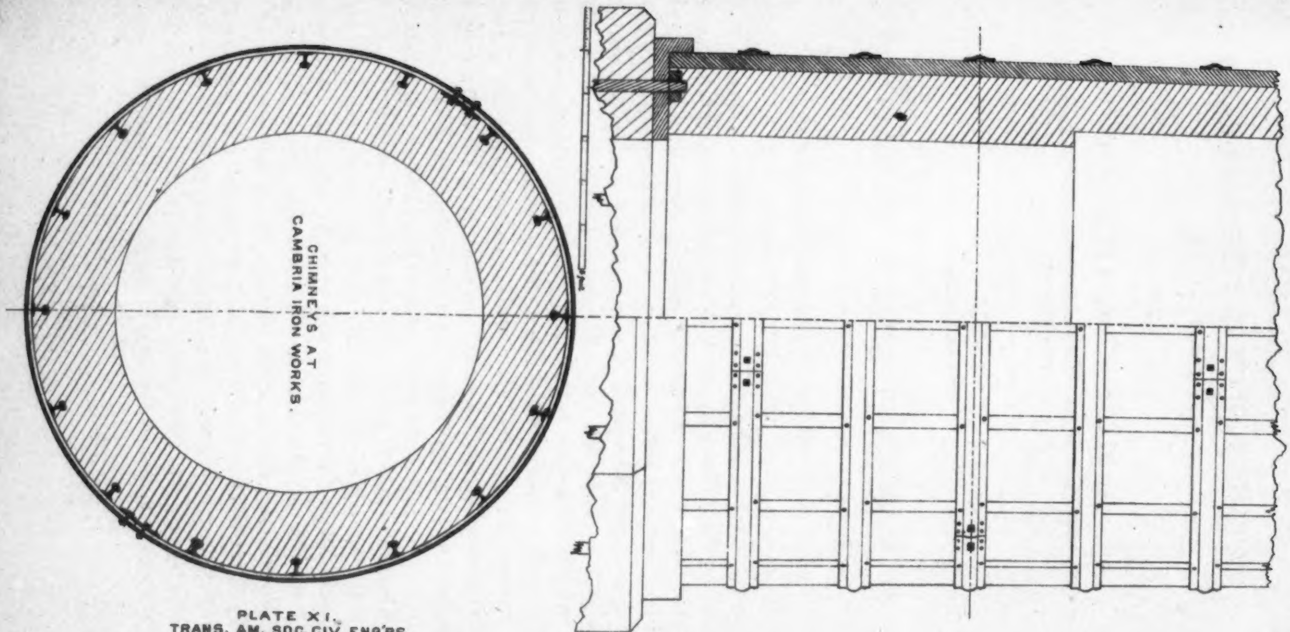


PLATE XI.
TRANS. AM. SOC. CIV. ENG'RS
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CHIMNEY CONSTRUCTION.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

302.
(Vol. XIV.—May, 1885.)

THE PROBLEM OF THE SUBMERGED WEIR.

By CLEMENS HERSCHEL, M. Am. Soc. C. E.

READ JUNE 17TH, 1885.

The problem consists in finding a formula which shall fittingly serve to compute the discharge over a submerged weir, from the data afforded by the experiment, or the gauging, in progress. The data for finding such a formula, to which it is intended to confine this paper, are the experiments made in 1848 by James B. Francis, M. Am. Soc. C. E., those made by Fteley and Stearns, Ms. Am. Soc. C. E., in 1877, and those made by Mr. Francis in 1883; described respectively in "Lowell Hydraulic Experiments," p. 102, in the Transactions Am. Soc. C. E., 1883, p. 101, and in the same, 1884, p. 303. Having had occasion to apply the formulæ given in the two papers last named, I was confirmed in my dislike to all the formulæ I had yet seen, as governing the case of discharge referred to, and resolved to seek a new one.

For this purpose I took Table XXV, of the Fteley and Stearns paper, and have recomputed Table III of Mr. Francis' paper. A close inspection of the latter will show that the quantities actually discharged during the several experiments do not enter into this table, and the recomputation had for its object to arrive at such quantities actually discharged. For this purpose I take the experiments of Table III, both previous and subsequent to each group of back-water experiments, during which there was no back-water. Find from them the value of the term $m\ A$, being the co-efficient of discharge through the orifices in the

wheel, m, multiplied by the sum of the areas of those orifices, A. Take an average of these values of $m\ A$. Then from such average value, and from the fall actually obtaining on the wheel during the back-water experiments, find the discharge for those experiments; being $= m\ A \sqrt{2gh'}$, if the notation of Table III be kept intact. From the actual discharges thus obtained, I have computed the co-efficient called n in Mr. Francis' paper, and the co-efficient called c in the paper of Fteley and Stearns. The results of the computations above described are exhibited in the table which follows:

TABLE I.

No. of the Experiment. 1883.	Actual Discharge during the Experiment	$m\ A$.	Co-efficient n.	Co-efficient c.	REMARKS.
13	96.05	3.2089	....	....	NOTE A. No back-water during these experiments; the discharge computed by weir formula, $Q = 3.33\ L\ H'^{\frac{3}{2}}$, and corrected for velocity of approach.
14	96.05	3.2110	....	....	
26	96.1	3.2134	....	....	
27	96.17	3.2142	....	....	
28	96.17	3.2143	....	....	
29	96.30	3.2182	....	....	
30	96.17	3.2149	....	....	
31	96.05	3.2100	....	....	
Average	....	3.2131			
19	96.23	"	0.6987	3.3775	NOTE B. Back-water during these experiments; the discharge computed by formula, $Q = m\ A \sqrt{2gh'}$.
20	96.22	"	0.7092	3.3817	
21	96.18	"	0.6171	3.3240	
22	96.09	"	0.5893	3.2711	
23	95.94	"	0.5671	3.1891	
24	95.68	"	0.6011	3.2479	
25	95.25	"	0.5852	3.1751	
21-25	95.83		0.5920	....	Average.
32	162.28	5.5643	....	....	NOTE A.
33	162.28	5.5639	....	....	
34	162.43	5.5701	....	....	
35	162.13	5.5653	....	....	
36	162.13	5.5703	....	....	
37	161.84	5.5626	....	....	
38	161.84	5.5662	....	....	
49	162.28	5.5569	....	....	
50	162.43	5.5643	....	....	
51	162.28	5.5643	....	....	
Average	....	5.5648			
40	161.71	"	1.0049	3.3766	NOTE B.
41	161.74	"	1.0621	3.3761	
42	161.68	"	0.7568	3.3782	
43	161.31	"	0.6188	3.3224	
44	161.18	"	0.5857	3.2607	
45	161.02	"	0.5849	3.2568	
46	161.83	"	0.6102	3.2937	
47	161.29	"	0.5638	3.1348	
43-47	161.33		0.5927	....	Average.

TABLE I—(*Continued*).

No. of the Experiment. 1883.	Actual Discharge during the Experiment	*m A.*	Co-efficient *n.*	Co-efficient *c.*	REMARKS.
52	207.40	7.2778	....	....	
53	207.24	7.2720	....	....	
54	207.40	7.2784	....	....	
55	207.08	7.2673	....	....	
56	207.24	7.2757	....	....	
57	207.08	7.2696	....	....	NOTE A.
58	207.40	7.2824	....	....	
59	207.40	7.2830	....	....	
74	207.40	7.2798	....	....	
75	207.40	7.2847	....	....	
76	207.08	7.2713	....	....	
Average	....	7.2765			
64	206.91	"	1.0813	3.3847	
65	206.93	"	0.9002	3.3856	
66	206.81	"	0.6808	3.3592	
67	206.73	"	0.6712	3.3634	
68	206.52	"	0.6307	3.3403	NOTE B.
69	206.27	"	0.6037	3.2948	
70	206.64	"	0.5876	3.2461	
71	206.77	"	0.5911	3.2542	
72	205.92	"	0.5837	3.2082	
73	205.91	"	0.5870	3.2177	
68-73	206.34		0.5973	....	Average.
77	231.33	8.2334	....	....	
78	231.18	8.2321	....	....	
79	231.18	8.2345	....	....	NOTE A.
83	232.17	8.2164	....	....	
84	232.33	8.2260	....	....	
Average	....	8.2285			
80	229.43	"	0.6064	3.2935	
81	228.16	"	0.5980	3.2537	NOTE B.
82	228.18	"	0.5965	3.2489	
80-82	228.59		0.6003	....	Average.
85	74.57	2.4792	....	....	
86	74.45	2.4767	....	....	
87	74.45	2.4789	....	....	
88	74.34	2.4768	....	....	NOTE A.
98	73.65	2.4723	....	....	
99	73.65	2.4732	....	....	
100	73.65	2.4749	....	....	
101	73.54	2.4723	....	....	
Average	....	2.4755			
91	74.07	"	0.6594	3.3449	
92	74.08	"	0.6435	3.3511	
93	73.91	"	0.5721	3.2399	
94	73.75	"	0.5572	3.1507	NOTE B.
95	73.54	"	0.5746	3.1599	
96	73.50	"	0.5713	3.1511	
97	73.07	"	0.5947	3.2061	
93-97	73.55		0.5740	....	Average.

If any one will take the pains to plot the values of n and of c just given, in comparison with the values of n and of c, deduced from the experiments of 1848 and of 1877, he will at once see that here is another of the frequent cases of a certain curve or formula, fitting two sets of experiments, where it absolutely refuses to fit them and a third and later set also. As regards values of n, I do not find them constant. n is equal to:

.5740	for experiments	93–97	of	1883
.5920	" "	21–25	"	"
.5927	" "	43–47	"	"
.5973	" "	68–73	"	"
.6003	" "	80–82	"	"

that is: it increases as the quantity discharged increases, but with ample variation among its several values for nearly equal quantities discharged, according as the amount of back-water varies, as may be seen by inspection of Table I.

Passing next to the construction of a new formula, it has seemed to the writer that there might well be a relation between the depth of water on the submerged weir, called d in the Fteley and Stearns paper, and the depth of water which would be formed on a weir of free discharge, to enable it to discharge an equal volume of water (in equal times, of course). This may be called the weir of equivalent discharge, and the depth on such a weir, [the whole operation to be based on the Francis formula for weir discharge, $Q = 3.33LH^{\frac{3}{2}}$], I have called H. I have further thought that such relation might vary only with respect to a variation of what Fteley and Stearns call $\frac{d'}{d}$, being the depth of back-water, divided by the total depth on the submerged weir. A computation made to test such product of the scientific imagination results in the following table:

TABLE II.

Number of Exp.	Experiments of the year	$\frac{d'}{d}$	$\frac{H}{d}$	Number of Exp.	Experiments of the year	$\frac{d'}{d}$	$\frac{H}{d}$	Number of Exp.	Experiments of the year	$\frac{d'}{d}$	$\frac{H}{d}$
1	1848.	0.023	0.9992	17	1877.	0.698	0.7785	64	1883.	0.015	1.0107
2	"	0.077	1.0048	18	"	0.767	0.7285	65	"	0.025	1.0108
3	"	0.100	1.0004	19	"	0.788	0.7130	66	"	0.065	1.0048
4	"	0.123	0.9946	20	"	0.797	0.7037	67	"	0.088	1.0045
5	"	0.249	0.9666	21	"	0.944	0.4888	68	"	0.164	0.9947
6	"	0.505	0.8785	22	"	0.975	0.3746	69	"	0.260	0.9744
								70	"	0.349	0.9485
1	1877.	0.063	1.0000	19	1883.	0.081	1.0078	71	"	0.350	0 9498
2	"	0.017	1.0014	20	"	0.075	1.0086	72	"	0.481	0.9048
3	"	0.042	1.0030	21	"	0.172	0.9907	73	"	0.489	0.9039
4	"	0.050	1.0054	22	"	0.252	0.9707	80	"	0.329	0.9619
5	"	0.081	1.0087	23	"	0.374	0.9317	81	"	0.479	0.9141
6	"	0.145	0.9988	24	"	0.618	0.8538	82	"	0.475	0.9145
7	"	0.189	0.9774	25	"	0.697	0.7942	91	"	0.052	1.0023
8	"	0.285	0.9560	40	"	0.015	1.0090	92	"	0.136	0.9994
9	"	0.294	0.9391	41	"	0.013	1.0092	93	"	0.254	0.9641
10	"	0.305	0.9495	42	"	0.045	1.0089	94	"	0.410	0.9152
11	"	0.372	0.9288	43	"	0.271	0.9781	95	"	0.568	0.8620
12	"	0.383	0.9280	44	"	0.267	0.9664	96	"	0.554	0.8670
13	"	0.413	0.9137	45	"	0.277	0.9640	97	"	0.764	0.7472
14	"	0.487	0.8821	46	"	0.439	0.9345				
15	"	0.634	0 8178	47	"	0.520	0.8775				
16	"	0.635	0.8187								

A plotting of the above table gives the diagram shown on Plate XII, and this diagram, read off at regular intervals, results in the table* next given.

TABLE III.

$\frac{d'}{d}$	$\frac{H}{d}$	$\frac{d'}{d}$	$\frac{H}{d}$	$\frac{d'}{d}$	$\frac{H}{d}$
0.00	1.000±0.000	0.35	0.944±0.016	0.70	0.787±0.012
.01	1.004±0.004	.36	0.941±0.016	.71	0.780±0.012
.02	1.006±0.006	.37	0.938±0.017	.72	0.773±0.011
.03	1.006±0.007	.38	0.935±0.017	.73	0.766±0.011
.04	1.007±0.007	.39	0.932±0.017	.74	0.758±0.011
.05	1.007±0 007	.40	0.929±0.017	.75	0.750±0.010
.06	1.007±0.007	.41	0.926±0.017	.76	0.742±0.010
.07	1.006±0.006	.42	0.922±0.018	.77	0.732±0 010
.08	1.006±0.006	.43	0.919±0.018	.78	0.723±0.010
.09	1.005±0.005	.44	0.915±0.018	.79	0.714±0.010 †
.10	1.005±0.005	.45	0.912±0.018	.80	0.703±0.010
.11	1.003±0.006	.46	0.908±0.018	.81	0.692±0.010
.12	1.002±0.006	.47	0.904±0.018	.82	0.681±0.009
.13	1.000±0.007	.48	0.900±0.018	.83	0.669±0.009
.14	0.998±0.007	.49	0.896±0.018	.84	0.656±0.009
.15	0.996±0.008	.50	0.892±0.018	.85	0.644±0.008
.16	0.994±0.008	.51	0.888±0.018	.86	0.631± ?
.17	0.992±0.008	.52	0.884±0.018	.87	0.618 "
.18	0.989±0.009	.53	0.880±0.018	.88	0.604 "
.19	0.987±0.009	.54	0.875±0.018	.89	0.590 "
.20	0.985±0.010	.55	0.871±0.018	.90	0.574 "
.21	0.982±0.010	.56	0.866±0.018	.91	0.557 "
.22	0.980±0.010	.57	0.861±0.018	.92	0.539 "
.23	0.977±0.011	.58	0.856±0.018	.93	0.520 "
.24	0.975±0.012	.59	0.851±0.018	.94	0.498 "
.25	0.972±0.012	.60	0.846±0.017	.95	0.471 "
.26	0.970±0.013	.61	0.841±0.017	.96	0.441 "
.27	0.967±0.013	.62	0.836±0.016	.97	0.402 "
.28	0.964±0.013	.63	0.830±0.016	.98	0.352 "
.29	0.961±0.013	.64	0.824±0.015	.99	0.275 "
.30	0.959±0.014	.65	0.818±0.015	1.00	0.000±0.000
.31	0.956±0.014	.66	0.813±0.014		
.32	0.953±0.014	.67	0.806±0.014		
.33	0.950±0.015	.68	0.800±0.013		
.34	0.947±0.015	.69	0.794±0.013		

* Observe, from the form of curve and table given, that the amount of back-water may be as high as 1-5 of the depth on the weir, without affecting the discharge ordinarily more than 2 per cent.

† The values given in this table below this line are not so well determined as those above the line.

I ought, perhaps, to say something in explanation and in advocacy of the somewhat peculiar form of Table III. It is intended to show, not only the best attainable or most probable results to be derived from the experiments available for making the table, but also to show plainly and concisely, and judging as far as one may from the same experiments, how far any single future experiment may be under liability to deviate from the results as now established. I submit to the Society and to the reader that civil engineers have been too negligent in a thorough and every-day appreciation of the fact that no measurement of any physical object can ever be called exact. It is beyond the power of human ingenuity, for example, to make a rod of metal or of any other substance which shall be exactly 1 foot long. It is still less feasible to describe, physically, the limits of a square foot, or of a cubic foot, and still less feasible to gauge cubic feet per second. By rights, all mention of any measurement performed should always be accompanied by a $\pm$ sign, followed by a figure indicating the limits within which the measurement may be presumed to be exact. It may be humbling to our scientific pride to do this, and it would no doubt fail to attract the dumb admiration of the multitude, but the resultant answer would be more truthful than long strings of decimals, however long they be spun out, when unaccompanied by a proper indication of the degree of exactitude actually attained.

The method indicated is especially applicable in the construction of formulæ from data afforded by only a limited number of available experiments. In the natural order of things, no such formula can represent *all* the experiments considered. With more experiments of the same sort, the co-efficients first found would ordinarily change. From the nature of the work done, a repetition of the experiment, using the same degree of care and exactitude, would not produce exactly the same result. Every co-efficient so determined should therefore be accompanied by a $\pm$ sign, and followed by a reading from the enveloping curves drawn on either side of the central curve, the enveloping curves to pass through the given points which are furthest distant from the curve representing the most probable locus of the curve deduced from all of the experiments.* In this way the resultant formula may at any

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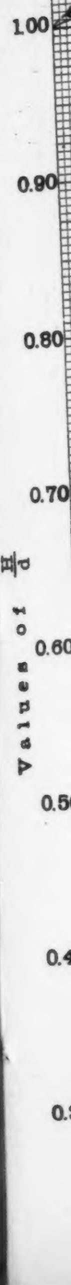
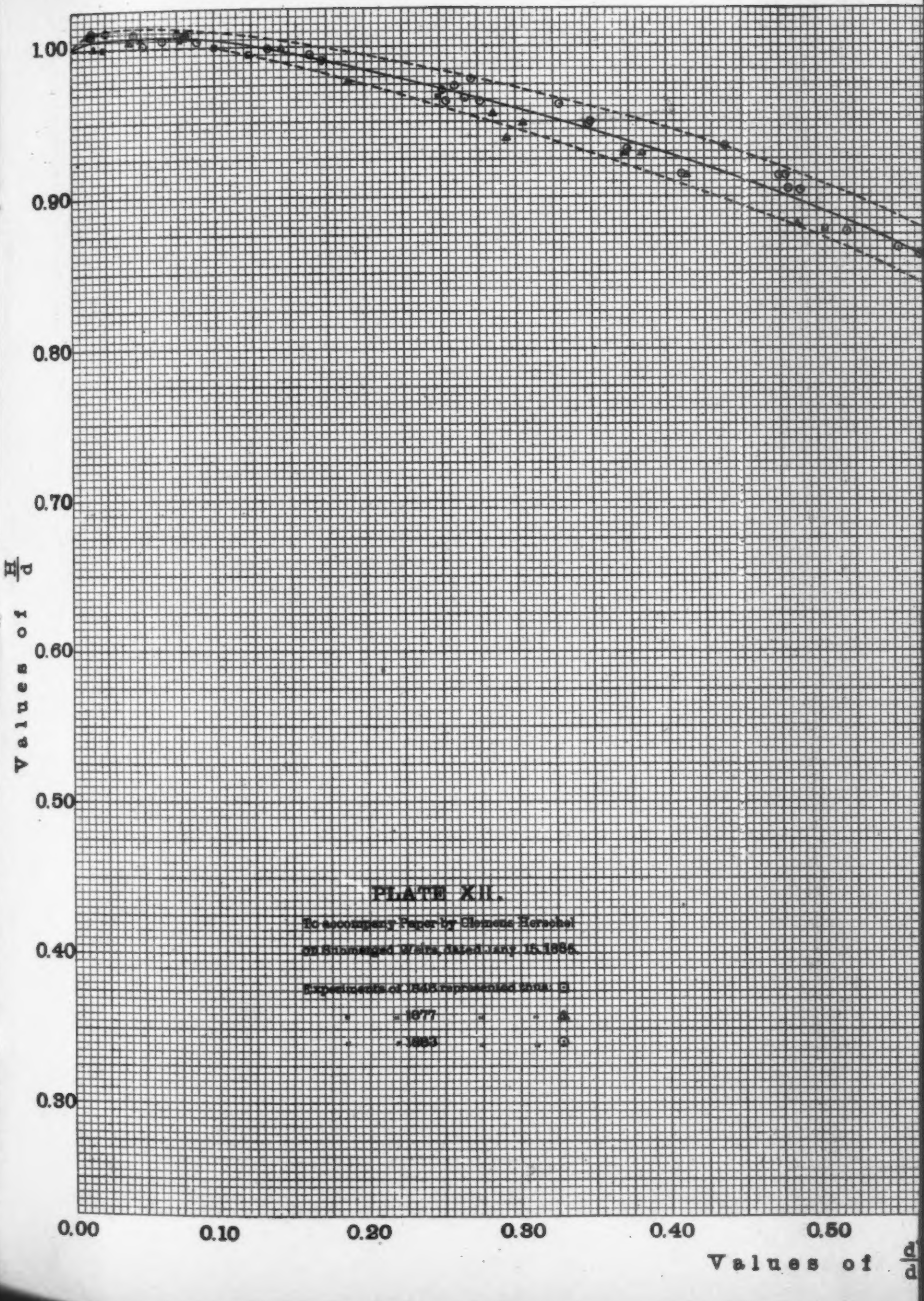
* In drawing the enveloping curves, in the present instance, I have not given full weight to experiment No. 9 of the 1877 experiments. It is apparently at fault for some unknown cause.

time be used to give an answer that will certainly be on the safe side. Or it may be used to give the answer most probably correct, judging from the information at hand to date; and this answer accompanied by a $\pm$ quantity, showing within what limits it *may be* at variance with the actual facts.

The answer given to the problem stated at the outset has therefore been in form of a table (Table III), which, put in form of a formula, would be $\frac{H}{d}=a$, or $H=ad$, with 100 values of a for a corresponding 100 values of $\frac{d'}{d}$. Instead of such a table of 100 values, a formula representing the relation between $\frac{d'}{d}$ and $\frac{H}{d}$ might, of course, be set up. It would result in a formula for H, giving its value directly in terms of d, d', and one, two or more constant co-efficients. But this, as a bit of burdensome juggling, with the aid of the method of least squares, I have thought needless to go into.





1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
Values of H/d
0.00
0.10
0.20
0.30
0.40
0.50
Values of d/d
PLATE XII.
To accompany Paper by Clemens Herschel
on Submerged Weirs, dated Jany 15, 1885.
Experiments of 1848 represented thus:
" " 1877 " "
" " 1883 " "

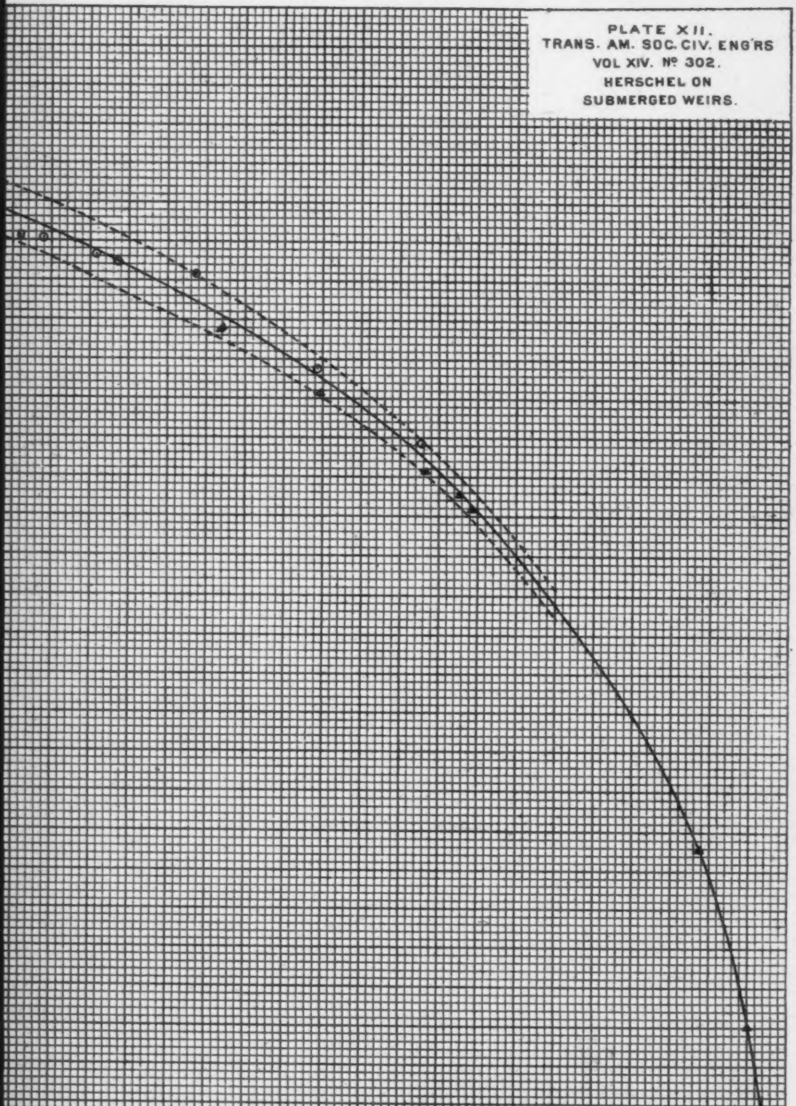


PLATE XII.
TRANS. AM. SOC. CIV. ENG'RS
VOL XIV. Nº 302.
HERSCHEL ON
SUBMERGED WEIRS.
.50
0.60
0.70
0.80
0.90
1.00
of $\frac{d'}{d}$